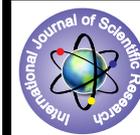


Design and Implementation of scaled down of Heterogeneous Spectrometers for Radio Astronomy applications



Engineering

KEYWORDS : Spectrometers, Astronomy, FPGA

P.Amar Singh

GURU NANAK INSTITUTE OF TECHNOLOGY, IBRAHIMPATNAM, HYDERABAD, ANDHRA PRADESH

G.Karthik Reddy

GURU NANAK INSTITUTE OF TECHNOLOGY, IBRAHIMPATNAM, HYDERABAD, ANDHRA PRADESH

ABSTRACT

We have developed a software package to automatically generate spectrometers with minimal user input. Spectrometer design is often done by building the instrument from scratch. We have automated this design, creating a parameterized spectrometer that only requires a recompile to implement a change in specification. This spectrometer combines FPGAs and GPUs, doing coarse channelization on the FPGA and sending each sub band to the GPUs for further processing. In this paper, we describe a radio astronomy instrument that is easily reconfigured to suit a variety of applications. This style of instrument design can be extended to a heterogeneous cluster running multiple processing algorithms at the same time. Many algorithms require the data to be broken up into sub bands before it can be processed by the server which can be done on the same FPGA.

1. INTRODUCTIO

The need for high bandwidth spectroscopy manifests in many different radio astronomy applications. Keeping up with increasing computation demands has often resulted in the specialized design of spectrometers. At the Collaboration for Astronomy Signal Processing and Electronics Research (CASPER), we have developed a software package to automatically generate spectrometers for a variety of applications. The CASPER FPGA libraries were developed to mitigate the need to redevelop common signal processing blocks for every new instrument [1]. Parameterized blocks such as FFTs and digital down-converters can easily be used to design many different instruments. Coupled with open source FPGA boards, such as the ROACH (Reconfigurable Open Architecture Computing Hardware), the CASPER libraries provide a useful toolbox for radio astronomy instrumentation development. This work extends the CASPER philosophy, demonstrating that entire instruments can be generated with minimal user input. Rather than designing a completely different instrument for every different specification, this software package is parameterized so a change in specification only requires a recompile.

The software package includes FPGA design and server software to do spectroscopy, as well as server benchmarks used to determine an optimal instrument configuration. Both the FPGA and server software are parameterized, allowing for rapid deployment of a working spectrometer that is configured to take full advantage of available computing resources. We implement the instrument on a heterogeneous cluster consisting of both FPGAs and GPUs to take advantage of the benefits provided by both platforms. High level parameters in this package allow us to use FPGAs while abstracting away implementation details spectrometer the FPGA. To give the user control over their data processing algorithm, an application specific GPU program can be written and easily interfaced with the existing receive software in the package.

2. RADIO ASTRONOMY APPLICATION

This instrument has a wide variety of potential applications due to the exibility of the server software. In this section, we describe a few specific applications than can make use of this package. In the search for extraterrestrial intelligence (SETI), the ability to keep up with changes in technology allows searching instrumentation to stay on the leading edge of sensitivity. SETI aims to process the max-978-1-4244-6051-9/11/\$26.00 ©2011 IEEE imum bandwidth possible with very high resolution spectroscopy. This instrument allows SETI projects to easily keep up with improvements on the telescope and increasing computational power. An increase in detector bandwidth, improving the breadth of the search, can be processed simply recompiling the FPGA design and distributing the extra sub bands to new servers. As computation improves, the instrument can be reconfigured to send more bandwidth to each computer, reducing the required cluster size, or improve the resolution of the instrument by doing a larger FFT on the server.

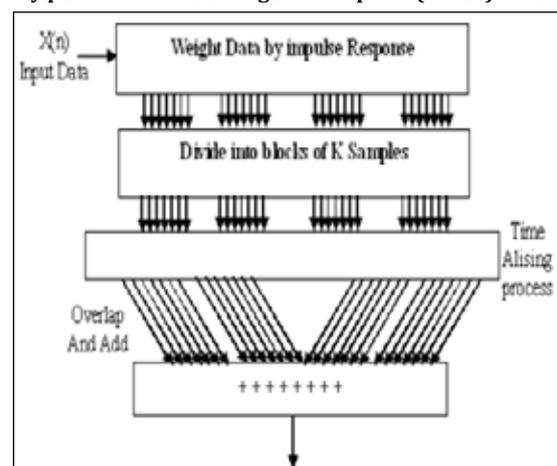
This design also has applications in pulsar science. The fast channelization on the FPGA with no data reduction makes it an ideal pulsar spectrometer, since no information is lost before sending the data to the servers. GPUs provide a good platform for pulsar processing algorithms such as coherent de dispersion. Which can easily be used as the processing function for the server software distributed in our package? Similar to SETI instruments, pulsar instruments designed using this package can also keep up with improvements in technology with a simple recompile.

3. INSTRUMENT ARCHITECTURE

The instruments generated with this package use a heterogeneous design, allowing us to benefit from the strengths of FPGAs and GPUs. The FPGA board is able to sample and process very high bandwidths that a single CPU or GPU would not be able to manage; once the FPGA has split up the band the GPU provides a platform that is easier than an FPGA to program but still provides high compute power.

A design called the Packetized Astronomy Signal Processor, or PASP, is run on the FPGA. PASP splits up the large band into smaller bands that can be processed using the shelf servers. The sub bands are put into packets on the FPGA and sent over a 10 gigabit Ethernet switch to a cluster of servers.

Poly phase Filter bank weight overlap add (WOLA) method



The servers receive the data from the switch and process it using spectroscopy software provided in the software package or special purpose application software written by the user and linked into the provided packet processing infrastructure. Figure 1 shows a high level view of a spectrometer that could be designed with this package.

In this example, a ROACH board divides the input band into 64

sub bands and sends them out to a 16 server cluster. An ADC is used to digitize data from the telescope and connects to the ROACH board via Z-DOK connectors. The digitized data is split into 64 sub bands and sent through a 10 gigabit Ethernet switch. Each server in the cluster receives and processes 4 sub bands.

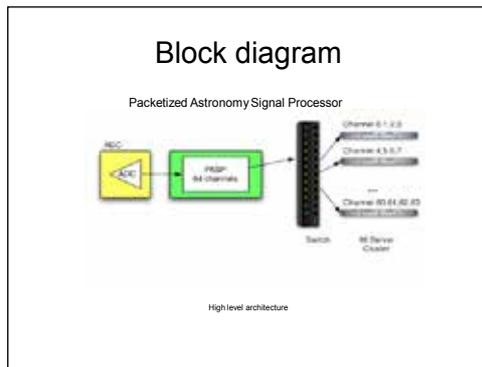


Figure 1: Example high level instrument architecture.

3.1 FPGA DESIGN

Figure 2 gives an overview of the dataflow through the FPGA. The FPGA interfaces to a single ADC board that simultaneously digitizes 2 signals. Each signal can be sampled at a maximum rate of 1Mps. The samples are sent into a polyphase filter bank (PFB), consisting of an FIR filter and an FFT, which breaks up the entire bandwidth sampled by the ADC into smaller sub bands. After dividing up the sub bands, the data is rescaled.

This step allows us to compensate for the shape of the analog filter feeding data into the ADC. After rescaling, the FPGA forms packets where each packet contains data from a single subband. The packets are sent out over CX4 ports to a 10 gigabit Ethernet switch.

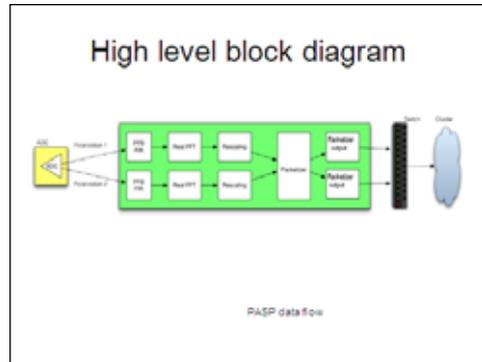


Figure 2: PASP Dataflow

PASP is designed for exibility. Building on the CASPER goal to automate the design of commonly used signal processing elements such as FFTs and digital down converters, PASP automatically designs an entire FPGA instrument using only a few parameters. The user can input the desired number of sub bands, CPU/GPU cluster size, and packet size and a new design is automatically generated in Simulink.

FIR FILTERS

FIR filters are one of two primary types of digital filters used in Digital Signal Processing (DSP) applications, the other type being IIR.

FFT filter

The FFT-based filters are basically FIR filters, but the filtering is not done in the time domain. The input signal is transformed from the time- into the frequency domain (using the FFT), the spectrum multiplied with the filter's frequency response, and the result is transformed back into the time domain (using the inverse FFT). Though this sounds more complicated than the

classic FIR implementation in a DSP, it's actually much faster if the filter has a high order (=a large number of coefficients). And it offers some special options -see the list of operations below- which are otherwise difficult to achieve.

3.2 SERVER BENCHMARKING

PASP has proven useful in many applications by itself, but the goal of automatically generating a spectrometer for any cluster requires more than just a reconfigurable FPGA design. It is midcult to determine what size the sub bands or the cluster should be without knowing how much data the target servers can receive and process. Our benchmarking tools are designed to quickly determine how much bandwidth a server is capable of handling so the PASP parameters can be set appropriately.

We have developed a general purpose benchmark to test the networking capability of a server. This test uses an FPGA design to generate 10 gigabit Ethernet packets and transmits them to the server under test. The FPGA design has a runtime programmable packet size and packet rate. The packet size is set to the largest size allowed by the server and the packet rate is initially set low and ramped up while the receive software running on the server checks for dropped packets. By searching for the highest bandwidth with no dropped packets, the maximum allowable data rate where the server should reliably receive all the data.

While specific processing algorithms may vary between scientific applications, an FFT benchmark provides insight into possible processing requirements for a variety of radio astronomy applications. We developed an FFT benchmark using CUFFT, the CUDA FFT library, which supports FFT of arbitrary sizes and allows them to be run in batches on the GPU. Our benchmark tests a variety of FFT sizes and batch sizes. In general, we have found that running larger FFTs and batching many FFTs together is necessary to fully take advantage of the computing resources on GPU. Running this benchmark allows us to determine the maximum bandwidth that can be processed with the available resources.

4. SOFTWARE DESIGN

Our package includes spectroscopy software that interfaces with the PASP design. This software receives

Data over an Ethernet port and transfers it from the CPU to the GPU. The GPU runs an FFT and then sends the data back to the CPU to be recorded. The GPU software, like the GPU benchmark, uses the CUFFT library to run FFT. The FFT size depends on the desired resolution for a specific application and an efficient batch size can be determined by running the FFT benchmark to and the best batch size for the given FFT size.

An initialization function is called before the data processing begins to do any setup needed by the processing function, and a corresponding destroy function cleans up once the processing is complete. In the spectroscopy software included in the package, the initialization function creates the FFT plan, the processing function calls CUFFT, and the destroy function deletes the FFT plan. Modifying the application run on the GPU simply requires a redefinition of these three functions. Using this interface, we successfully replaced the CUFFT processing with software developed for SETI searches designed by Kondo et al. [3].

5. CONCLUSIONS AND FUTURE WORK

In this paper, we describe a radio astronomy instrument that is easily reconfigured to suit a variety of applications. This style of instrument design can be extended to a heterogeneous cluster running multiple processing algorithms at the same time. Many algorithms require the data to be broken up into sub bands before it can be processed by the server which can be done on the same FPGA. Using multicast packets, multiple servers can subscribe to the same sub bands generated on by PASP and process them in different ways.

REFERENCE

[1] A Parsons et al. Petaop/second fpga signal processing for seti and radio astronomy. Signals, Systems and Computers, 2006. ACSSC '06. Fortieth Asilomar Conference on, pages 2031 { 2035, 2006. | | [2] S. M. Ransom, P. Demorest, J. Ford, R. McCullough, J. Ray, R. DuPlain, and P. Brandt. GUPPI: Green Bank Ultimate Pulsar Processing Instrument. In American Astronomical Society Meeting Abstracts #214, volume 214 of American Astronomical Society Meeting Abstracts, December 2009. | | [3] Hiro fumi Kondo, Eric Heine, Masao Okita, Dan Werthimer, and Kenichi Hagihara. A multi-gpu spec trometer system for real-time wide bandwidth radio analysis. |