Compression of Visibility Data for Murchison Widefield Array.

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Abstract. The Murchison Widefield Array (MWA) is a new low frequency radio telescope operating on the Square Kilometre Array site in Western Australia. MWA is generating tens of terabytes of data daily. The size of the required data storage has become a significant operational limitation and cost. We present a simple binary compression technique and a system for the floating point visibility data developed MWA. We present the statistics of the impact of such compression on the data with the typical compression ratio up to 1:3.1.

1. Introduction

The MWA is one of the Square Kilometre Array (SKA) precursor radio telescopes located in the desert in Western Australian. MWA is an interferometer type radio telescope with the longest baseline 2.9 km. It is optimised for the observations of very wide fields of sky between 200 and 2500 square degrees, and the frequencies between 80 and 300 MHz, with a processed bandwidth 30.72 MHz for both linear polarisations (Tingay S. et al. 2013). The MWA works without any moving parts, the primary beam is formed by electronically adjusted phases of the 16 bow-tie dipole antennas that form a small phased array known as a tile. The complete array of 128 tiles provides about 2000 m$^2$ of collecting area at 150 MHz.

Figure 1 shows the generic data flow in MWA digital backend system. The MWA implements a hybrid, distributed FX correlator outputting complex visibilities at 10–40 KHz frequency resolution integrated to 0.5–2 sec as required.

Each visibility is a complex number representing the amplitude and phase of a signal at a particular point in time within a frequency channel. For a given channel at each time step, the correlator carries out $2N \times (N + 1)$ pair-wise cross-correlation and auto-correlation (Wayth et al. 2009), where $N$ is the number of tiles. Since a visibility is a complex number, it is stored as 2 single precision (32 bit) IEEE 754 floating point data type values. The typical data rate of visibility data, for example, for 30.72 MHz bandwidth, 10 KHz spectral resolution and 2 second integration time is 387 MB/s. The Data Capture software component captures the data, forms memory-resident FITS files for each correlator dump, and passes the files to NGAS-Client (Wu et al. 2013). The data is then transferred via a dedicated optical fibre to Perth, and then further redistributed to other archives.
2. Floating Point Errors and Compression

During the F-stage of correlation the integer input from the telescope’s hardware is converted to floating point output due to the division operations. Such conversion is not precise due to the limitations of IEEE 754 format. For example, a division by a prime number 127 cannot be stored in IEEE 754 format with an infinite precision. Such errors have a systematic nature, and propagate and accumulate further down in the processing pipeline.

Furthermore, IEEE 754 floating point format is poorly compressible. Figure 2 shows a fragment of floating point output of MWA correlator. Only the bytes in bold can be compressed with a binary compression algorithm, which typically gives not more than 25% compression. At the same time, usage of IEEE 754 floating point format creates a significant redundancy in the form of storing the data whose origin is integer.
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Recognising this, we have developed a simple but efficient compression algorithm specifically for MWA visibility data dubbed *uvcompressed*. Figure 3 outlines the steps in the algorithm.

1. First, all the values scaled by an optimal factor that is typically ranges from 1 to 1000. The optimal scaling factor mostly depends on the number of integrations inside the correlator.
2. Then the values are rounded as per "half round up” method and converted to int32 data type. As it can be seen from Figure 4, there are now many more bytes that a binary compression is able to compress.
3. *cfitsio* (White, R.L. et al 2012) library had been used to compress the resampled data due to the fact that the correlator outputted the data as a set of FITS (Wells & Greisen 1979) files. Equally, other binary compression software could be used to achieve the compression, but due to the fact that *cfitsio* was already used, the library has allowed the compression and decompression to be done completely transparently for the end user – no other software had to be changed.

*RICE* and *GZIP2* compression options available in *cfitsio* had been tested with *RICE* been found performing slightly better for optimal scaling factors. Table 1 shows the typical compression ratios, as well as the percentage of affected data in tests. The “affected” is referring to such a data which uncompressed value is not equal to the original value.

| Scaling factor | Data affected (%) | Compression Ratio (RICE) |
|----------------|-------------------|--------------------------|
| 1              | 1.35              | 1:3.1                    |
| 4              | 1.52              | 1:2.6                    |
| 10             | 1.52              | 1:2.3                    |
| 100            | 1.08              | 1:1.9                    |
| 1000           | 0.23              | 1:1.6                    |

Table 1. Typical compression ratios
3. Conclusion

*uvcompress* algorithm achieves high compression ratio what has allowed MWA to reduce the storage size.

References

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