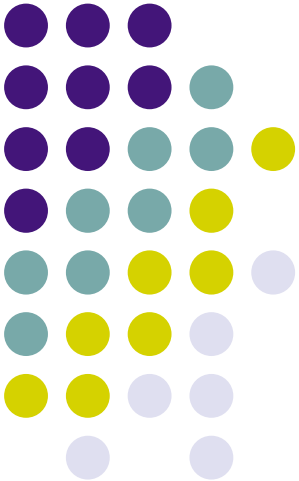
Phased arrays in DiFX

Status, plans and applications



Overview

- Phased array overview
- Motivations to use DiFX for phased array studies (DiFX-phased)
- Current drivers
- Plumbing DiFX for phased array calculations
- Current status
- Future expansions

Phased array overview

- A phased array is nothing more than coherent addition of antenna voltages from individual elements of an array
- Generally speaking, two complications:
  - The data has been quantised and sampled
  - There is an unknown time- and frequency-dependent phase offset between the antenna elements that must be corrected before the summation
    - In order of hassle: digital electronics, analog electronics, atmosphere/ionosphere

Motivations. 1

- Overlap: Up to and including the channelisation step, phased array and correlation is identical
- The “FX” part of DiFX is a tiny portion of the total codebase - the majority is the housekeeping (data movement, unpacking, delay calculation…)
- Thus by implementing in the same package a lot of infrastructure can be shared

Motivations. 2

- Other motivations are basically the same as for the initial DiFX concept in 2005 - writing software is quicker, easier and more maintainable/ upgradeable than a hardware solution
- Finally, any phased array needs a correlator at some point to provide the phasing info
  - DiFX offers the opportunity to tightly couple this step for increased efficiency

Current drivers for DiFX-phased

- Two projects, both long baseline, who wish to phase large apertures for high sensitivity pulsar observations
  - The Large European Array for Pulsars (LEAP) is funded through the European Pulsar Timing Array, and has considerable resources
  - A similar but much more informal, student-driven project with the Long Baseline Array is being headed up at Curtin University

LEAP

- LEAP aims to provide illuminated aperture equivalent to Arecibo (~200m) but fully steerable, by summing all the big dishes in the EVN (Effelsberg, Jodrell, WSRT, Nancay, Sardinia)
- Key to meeting EPTA goals for detection of gravitational waves

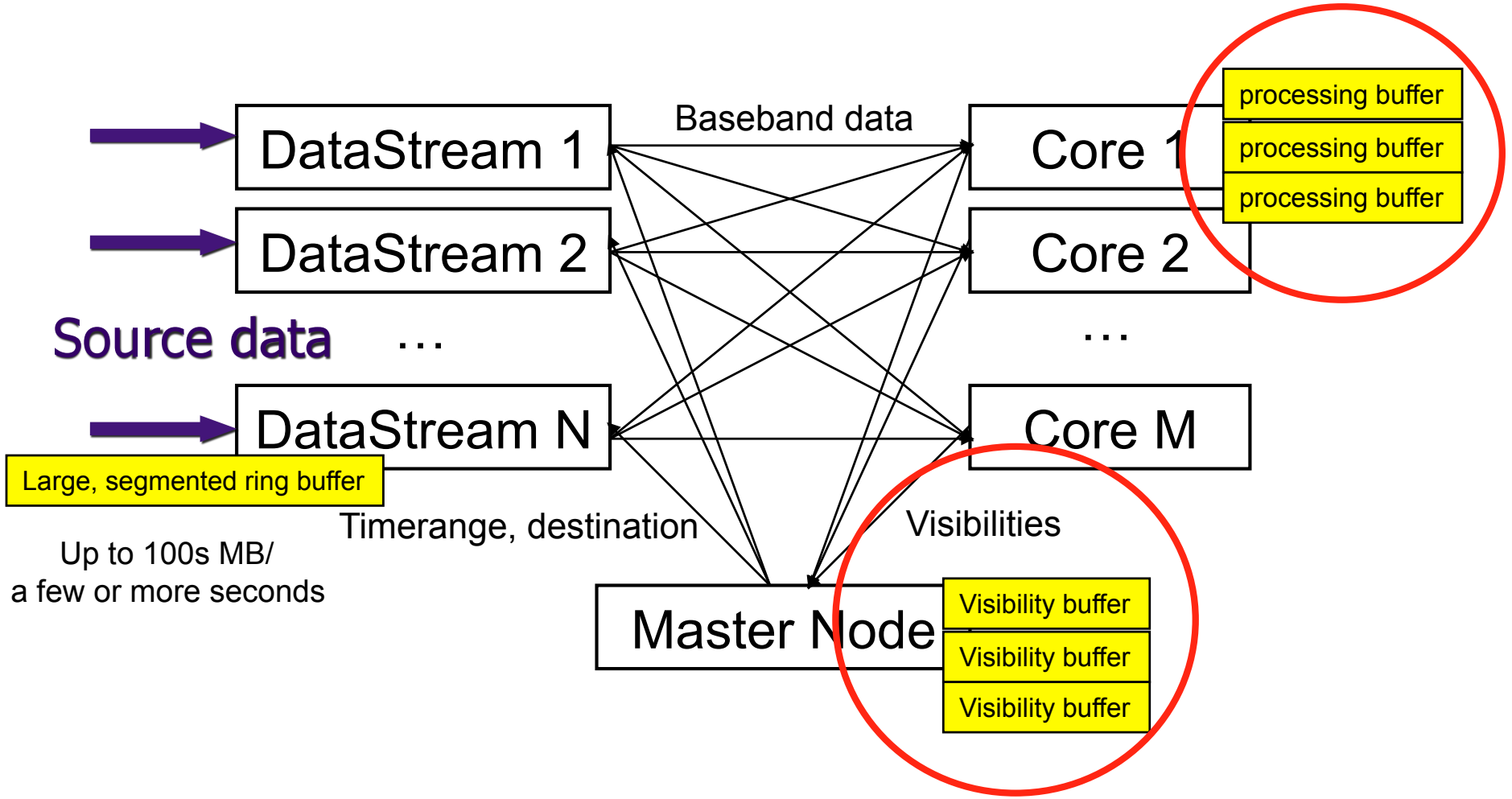
DiFX-phased plumbing

- The inputs for DiFX-phased are exactly the same as for normal DiFX operations: quantised, sampled data
  - VLBI format or custom new unpackers
- Two potential output formats:
  - Reconstructed time series. After summation of the filterbank data, inverse FFT + optionally complex->real transform. Most general, more work, higher data rate.
  - Frequency domain filterbank data (integrate or not). Quicker/easier, good for pulsar searching, but cannot coherent dedisperse

DiFX-phased plumbing

- Time domain output format:
  - Suggest VLBI Data Interchange Format (VDIF). Can be fed back into DiFX or DiFX tools, flexible, simple
- Frequency domain output format:
  - As yet undetermined. Probably a pulsar data format would be best (PSRFITS?)
- For either data format, handling of the data return from processing nodes to manager, and then writing out, must be completely different

DiFX-phased plumbing



DiFX-phased plumbing

- The final piece of the plumbing puzzle is the provision of extra information necessary to phase the array
- In the ideal case of a nice digital backend with narrow fractional bandwidth, a single delay correction would be sufficient
- In the real world, analog electronics and/or wide bands at low frequencies may require different delay corrections for different bands, or even quadratic corrections due to the ionosphere!

DiFX-phased plumbing

- Some additional optional lines in the DiFX model files (.calc, .im) will be needed to fully supply the general case
- This is still to be fully determined and implemented, but is conceptually very simple
- Calculating these corrections in the first place requires correlation on a sufficiently bright source, plus a fringe fit, plus preferably some method of automated transfer of the solutions into the DiFX system

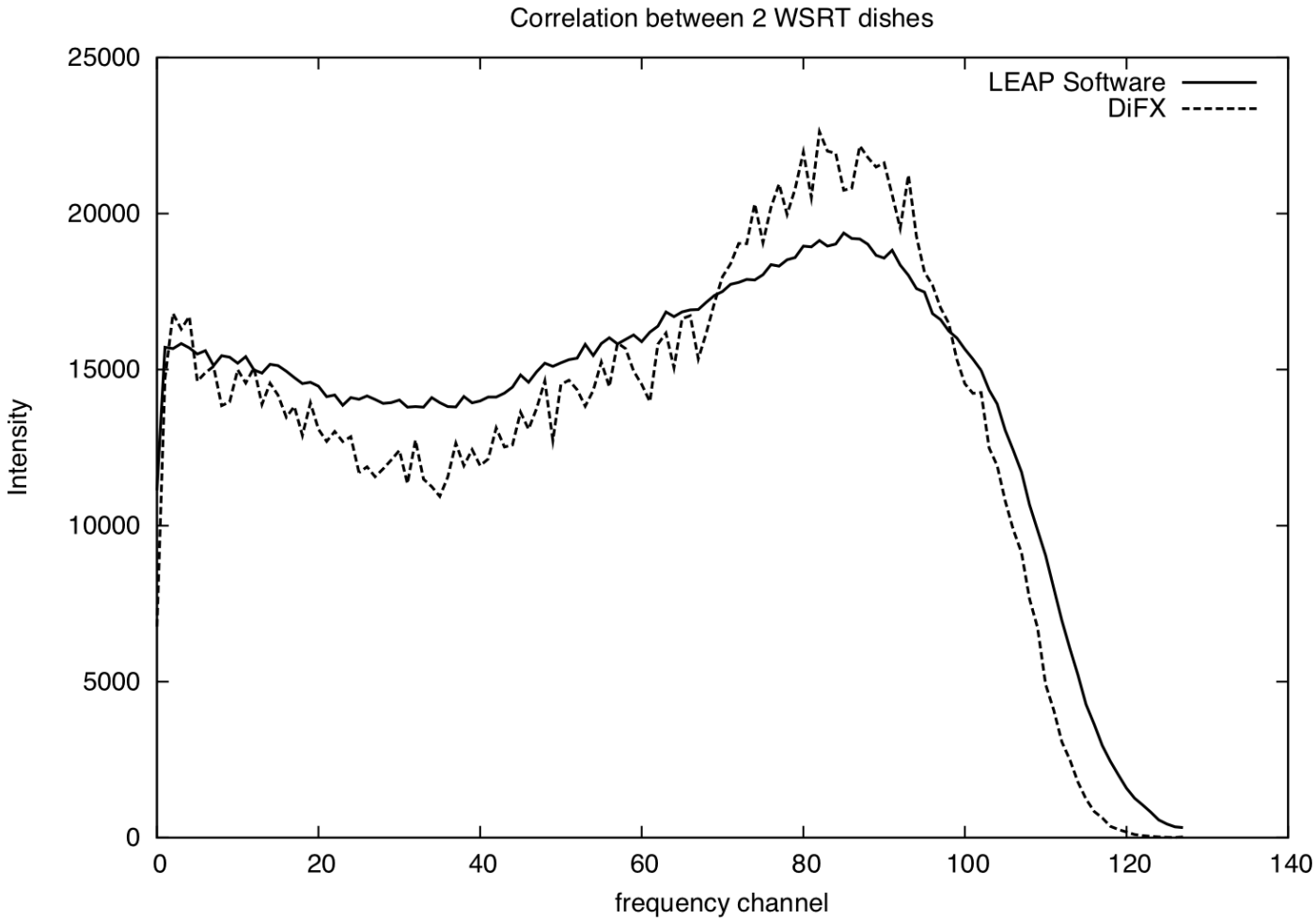
Current status

- The Australian team is still getting set up, so this status will focus on LEAP
- I have been providing assistance and feedback, but will not do all the coding
- At this stage, progress has been unfortunately slow:
  - Stubs have been put in place in DiFX for calculating result lengths, some infrastructure begun for shuffling the data between Core, Manager
  - The LEAP personnel have been stuck on getting data from their pulsar backend into DiFX (i.e. stage 1, correlation for delays)

Current status

- The baseband data which the LEAP team is using is from the PUMA2 pulsar instrument on WSRT
- They are strongly in favour of using their pulsar backends in preference to the VLBI systems (wider bandwidths)
- However, they have found it difficult to write a working unpacker for the PUMA2 format (it is complex sampled, with a fairly simple header)
- Autocorrelations don’t match - probably a bit or byte ordering problem

Current status



Current status

- LEAP not concerned about performance, since they will operate at relatively low duty cycle, so I have encouraged them to switch to a PUMA2->VDIF offline converter to make testing easier
- Underway now, progressing slowly
- Once this is working, LEAP and/or Curtin will have to tackle the remaining work:
  - DiFX side: add antenna data, send phased results (focus on time domain output format)
  - Outside DiFX: automated calculation/transfer of delay/phase solutions

Future work

- Once a ‘two-pass’ system of correlation then phasing is working smoothly, it would be a great extension to allow both correlation and phasing simultaneously
- Would require further “plumbing” changes to return/write both types of data at once, but no other new coding
- Somewhat useful as a check, but the real killer application would be realtime

Real-time phased array

- DiFX already has the infrastructure in place to modify clock values mid-correlation (used for eVLBI; not yet extensively)
- Thus if both phased array and correlation were taking place simultaneously, and real-time fringe-fitting was being performed… You could update the phasing in real time! No extra work needed on the DiFX side, all in ‘post-processing’

Conclusions

- There are good science applications that need a “VLBI phased array”, and DiFX offers an easy option to get that capability
- Work is progressing slowly - as usual, the biggest problems are managing the data formats and the metadata
- Initially a two-pass correlation -> phasing approach will be taken, but ultimately realtime phasing should be possible