A Real-time Software Broadband Beamformer on the IBM Cyclops Multiprocessor System
Objectives

• Design and implement a real-time broadband beamformer in software

• Test and evaluate the performance achievable by the software beamformer
Requirements

- Bandwidth of several MHz
- 2 Polarisations
- Steerable multiple beams
- Real time processing
The processing platform
IBM’s Cyclops System:

- Multi-Node system
- 3D grid configuration
- Max size 24X24X24 nodes
- Each node has one multi-processor Cyclops chip
Cyclops Capabilities

• 500 MHz system clock frequency

• 80 GFLOPS peak processing power

• 8 GBytes/s data throughput per port
Broadband Beamforming
Broadband Beamforming

- Based on narrowband beamforming
- Poly-Phase filters are used to split the signals into narrow frequency bands
- Narrowband beamformers are used to process each frequency band
Typical Broadband Beamforming Scheme

Signal from Antenna → Poly-Phase filter bank → Data reorganisation → Calibration → BeamForming

Poly-Phase filter bank → Calibration → BeamForming

Signal from Antenna → Poly-Phase filter bank → Calibration → BeamForming

One antenna all frequency bands

All antennas one frequency band

All beams one frequency band
Problem

• Data redistribution/reorganisation is complex and it limits the performance and the scalability.

• The reason is that it requires a communication bandwidth proportional to the product of the number of antennas by the sampling frequency.
Our Beamforming Scheme

Signal from Antenna
Signal from Antenna

Poly-Phase
Poly-Phase filter bank

Signal from Antenna
Signal from Antenna

Poly-Phase
Poly-Phase filter bank

Signal from Antenna
Signal from Antenna

Poly-Phase
Poly-Phase filter bank

Signal from Antenna
Signal from Antenna

Poly-Phase
Poly-Phase filter bank

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Calibrate and BeamForm 2 antennas

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Calibrate and BeamForm 2 antennas

Calibrate and BeamForm 2 antennas

Calibrate and BeamForm 2 antennas

One antenna, all frequency bands

Partially formed beams, all frequency bands

Fully formed beams, all frequency bands
Advantages

- No data redistribution/reorganisation

- Very scalable: The number of antennas can be increased easily

- The communication bandwidth is proportional to the product of the sampling frequency by the number of beams
Beamformer Mapping
Logical Mapping
Physical Mapping on the Cyclops System

- Unused link
- Used link
- Unused node
- Outer Node
- Inner Node
- Centre Node
Data Flow

OffChip DRAM

Beamforming Coefficients

Input Buffer

Processing

Output Buffer

Output Port

Cyclops

Outer Node

Input Port

Input Buffer

Processing

Output Buffer

Output Port

Cyclops

Inner Node

Input Port

Input Buffer

Processing

Output Buffer

Output Port

Cyclops

Centre Node

Input Port

Input Buffer

Processing

Output Buffer

OffChip DRAM
Software Development
Software Development

- **Kernel**
  - Light weight
  - Fast
  - Provides full access to all resources
  - Tested on a real Cyclops blade

- **Library**
  - Simple
  - Efficient
  - Fast
  - Compile-time parametric
  - Tested on a real Cyclops blade

- **Beamforming Application**
Application development work flow

Cyclops Kernel → Cyclops GNU C Compiler → Cyclops Library

Cyclops Program

Cyclops Executable

Cyclops Functionally Accurate Simulator
The Beamformer Implementation

- 2 Polarisations
- 1, 2, 4 or 8 beams (more is possible)
- 1X8 bits input data size and 2X8 bits output data size
- Mixed arithmetic precision:
  Coefficients are applied in double floating-point precision and partial-beams accumulated in 8 bits integer format
- On-the-fly updatable beamforming coefficients
- Independent from array geometry and antenna choice
Test and evaluation
Simulation Setup

MATLAB

Broadband Beamforming Simulation Program

Generate Input files (Signals + Coefficients)

Beamform Signals

Compare and Display Results

Cyclops Executable

Cyclops Simulator

Output file (Beamformed Signals)
2 Polarisations, 2 Frames, 8 Beams per frame, 64 Frequency bands per beam.
Simulation Results (Zoom)

Polarisation 1

Polarisation 2
The beamformer obeys the following formula:

$$2 \times \text{NumBeams} \times \text{NumPolarisations} \times \text{Bandwidth} \leq K$$

(K is the total data rate achievable by the program)

- $K \approx 1.28 \text{ GB/s}$ (estimation based on simulations)
  
  $\Rightarrow \text{NumBeams} \times \text{Bandwidth} \leq 320$

- For example for 8 beams, 2 polarisations, max 40MHz per beam. For 1 beam it’s 320MHz.
Conclusions and future work
Conclusions

- A real-time software broadband beamformer has been demonstrated
- A significant software development was required to achieve good performance
- The I/O bandwidth is the main performance limiting factor
- Scalability is very limited on a 3D grid configuration
Future work

Test a 2X8 input Beamformer on a 3X3X3 nodes Cyclops system