GR- Router : A Distributed GNU Radio Framework

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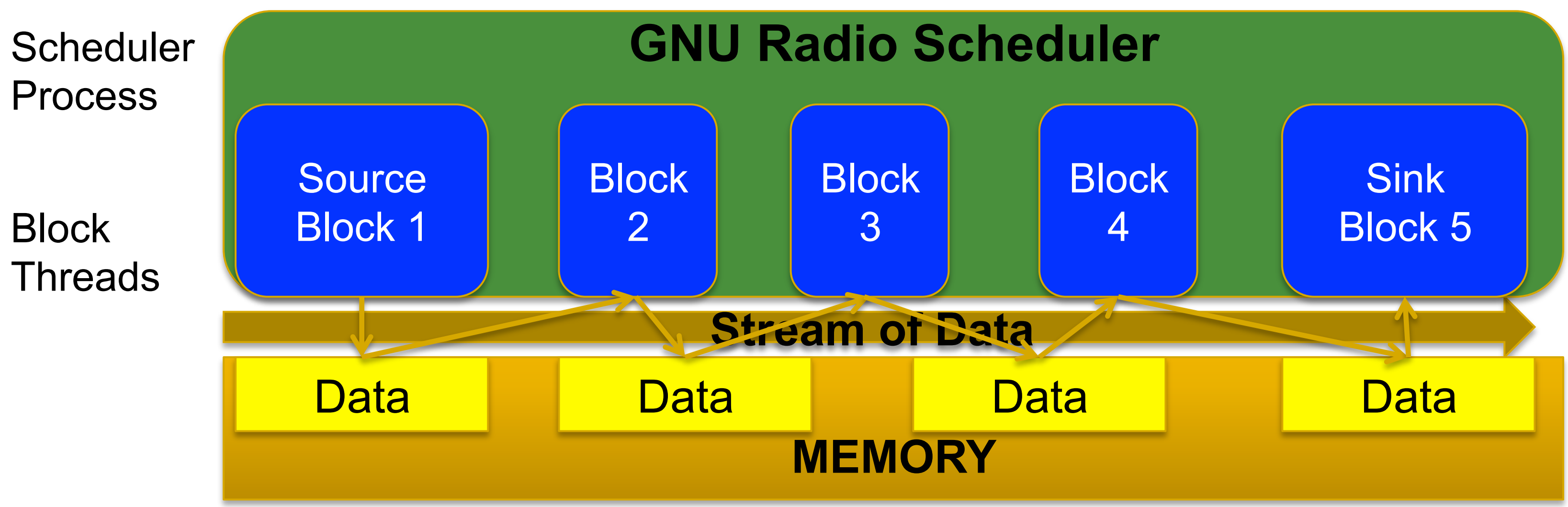
High-Performance Low-Power

Outline

- **Background**
- **Problem Statement** : Limited scalability in high-throughput shared-memory SDR system.
- **Solution** : Distribute the SDR system with GR-Router.
- **Example Implementation** : Test with GR-LDPC.
- **Future Work**

Background

- **GNU Radio**
  - Is an open-source software development toolkit.
  - It provides DSP blocks for SDR applications.
  - Each GNU Radio block is spawned as an independent processing thread which uses inter-thread communication mechanisms (via the scheduler) to share data between blocks.



The Problem

- Funding Source: Confidential high-throughput SDR communications system (multi-MIMO) that runs on a high-end, multi-core x86 processor (dozens) server with high-end memory configuration.

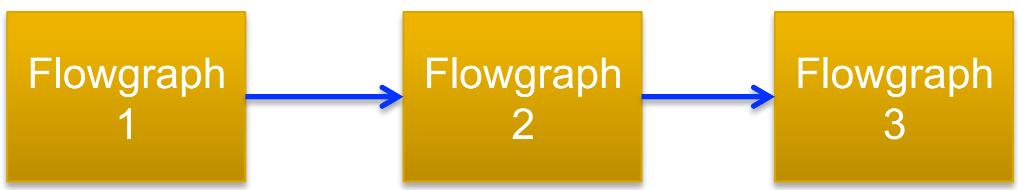
- They found that their throughput scales poorly as CPU count and memory are increased; they could not support additional real-time channels by introducing more hardware (within reason).

- After debugging and analysis, the problem was found to be <u>memory bandwidth contention</u>.

- Problem: Shared-memory system scales poorly with thread count.

Potential Solutions

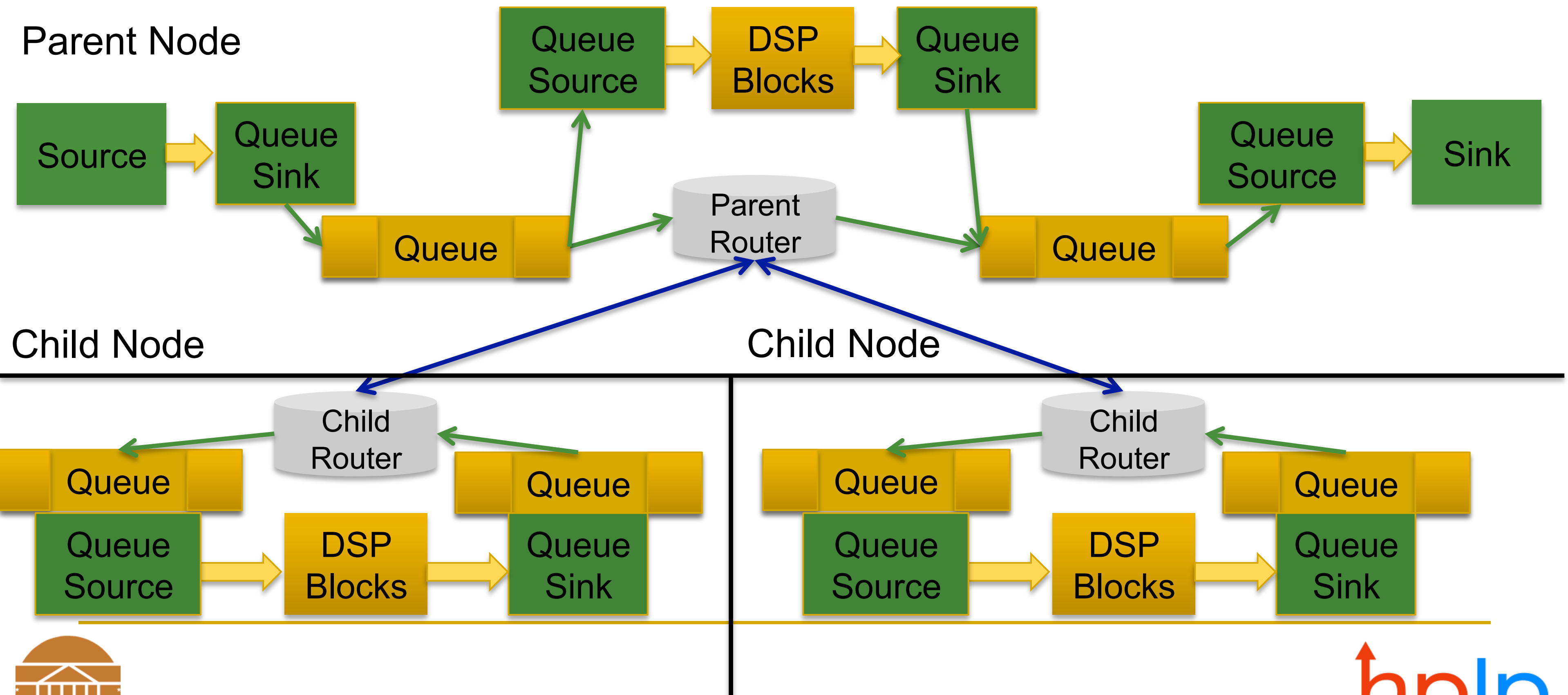
- Distribute block threads across disjoint memories and then use message passing between partitions.
  - Use existing TCP/UDP blocks and break flowgraph into networked chain
    - No dynamic load balancing; bottleneck slows down the entire system.



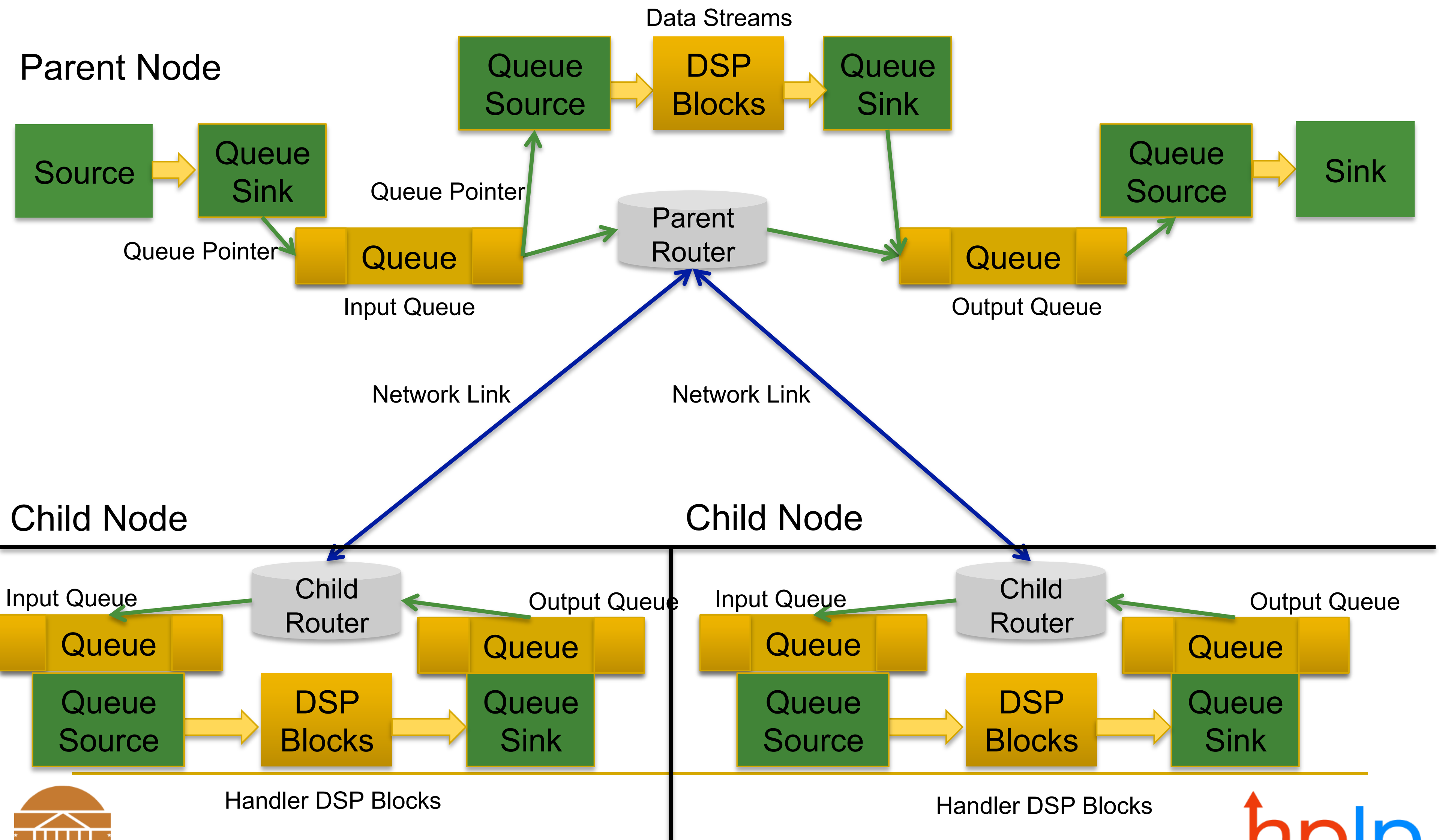
  - Instead use dynamic load-balancing to distribute the workload across multiple nodes; with the nodes running redundant blocks.

Solution: GR-Router

- GR-Router: Distributed GNU Radio framework
- Distributes the DSP workload across multiple machines tied to a common communication network



Terminology



Parent Code

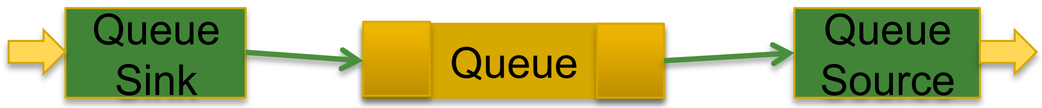
```
// Populate input queue
tb->connect(src, 0, throttle_0, 0);
tb->connect(throttle_0, 0, input_queue_sink, 0);

// Handler Code
tb->connect(input_queue_source, 0, decoder, 0);
tb->connect(decoder, 0, unpacked2packed, 0);
tb->connect(unpacked2packed, 0, output_queue_sink, 0);

//Order and sink results
tb->connect(output_queue_source, 0, throughput, 0);
tb->connect(throughput, 0, sink, 0);
tb->run();
```

Child Code

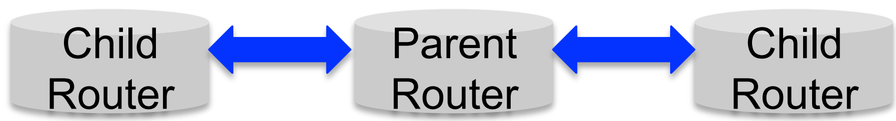
```
// Handler code
tb->connect(input_queue_source, 0, decoder, 0);
tb->connect(decoder, 0, unpacked2packed, 0);
tb->connect(unpacked2packed, 0, output_queue_sink, 0);
tb->run();
```

Blocks in GR-Router

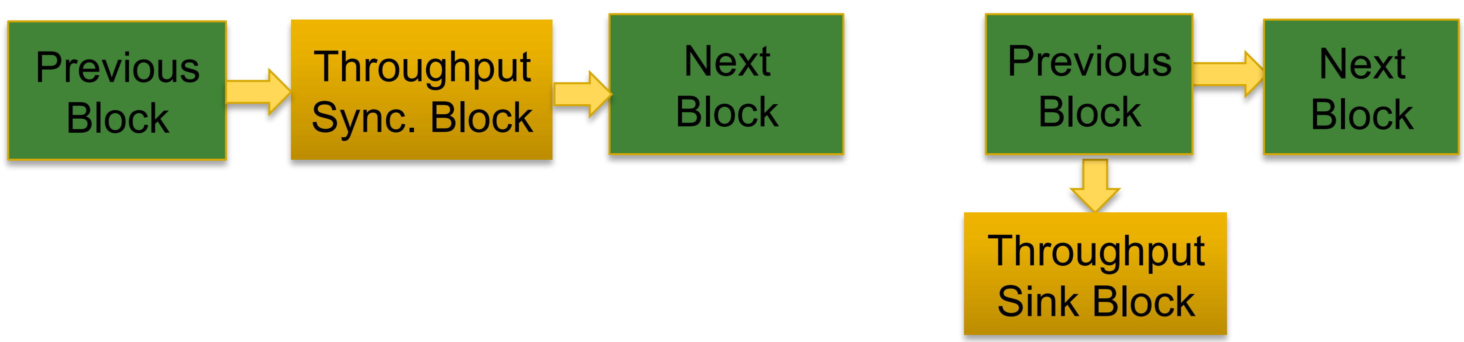
- Queue Source and Sink Blocks



- Parent & Child Router Blocks

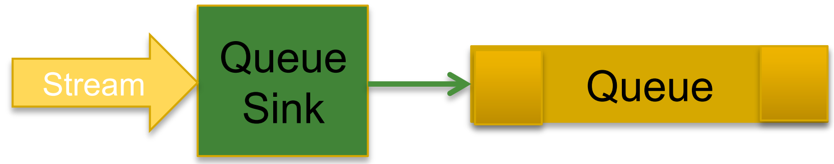


- Sync and Sink Throughput blocks



Queue_Sink Blocks

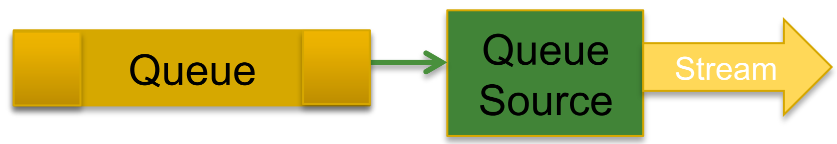
- **Queue Sink**: Converts stream to segments; pushes them onto queue
  - **Input**: Stream of data
  - **Output**: Pointer to queue
  - Supports reconstructing index
- **Segments**: Defined within the queue sink and source



Type 1 Msg.	type	index	size	Data[] : 768 floats	
Type 2 Msg.	type	index	size	Data[] : 50 bytes	
Type 3 Msg.	type	index	size	Data[] : 50 bytes	weight

Queue_Source Blocks

- **Queue Source**: Converts segments from a queue to streaming data
  - **Input**: Pointer to queue
  - **Output**: Stream of data
  - Supports ordering by index, and preserving index across stream with stream tags.



Type 1 Msg.	type	index	size	Data[] : 768 floats	
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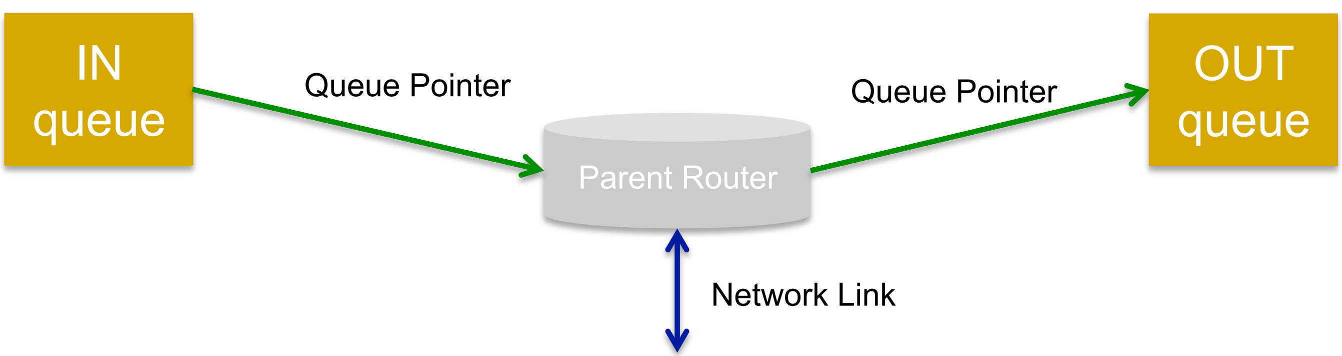
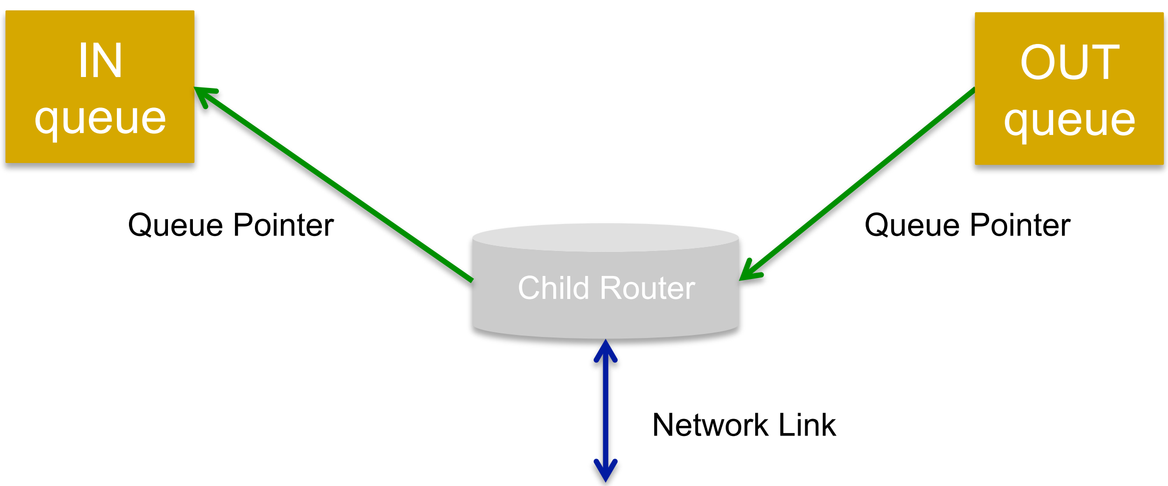
Parent_Router Block

- **Parent Router**: evenly distributes data segments among children
  - Keeps track of childrens' weights and distributes segments from the IN queue to balance the network.
  - Receives result segments from children (containing their 'weight')
  - **Input**: pointer from IN queue
  - **Output**: pointer to OUT queue
  - **Network Link**: Connection to Children.



Child_Router Block

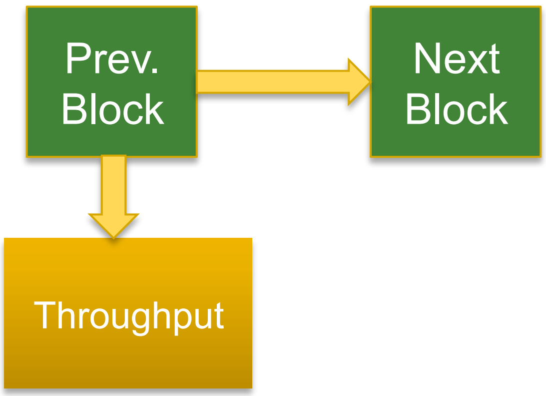
- **Child Router**: computes segments and returns results to Parent with weight.
  - Keeps track of current ‘busy-ness’, and sends weight to Parent
  - **Input**: Pointer from OUT queue
  - **Output**: Pointer to IN queue
  - **Network Link:** Connection to parent.



{Inline, Sink}_Throughput Blocks

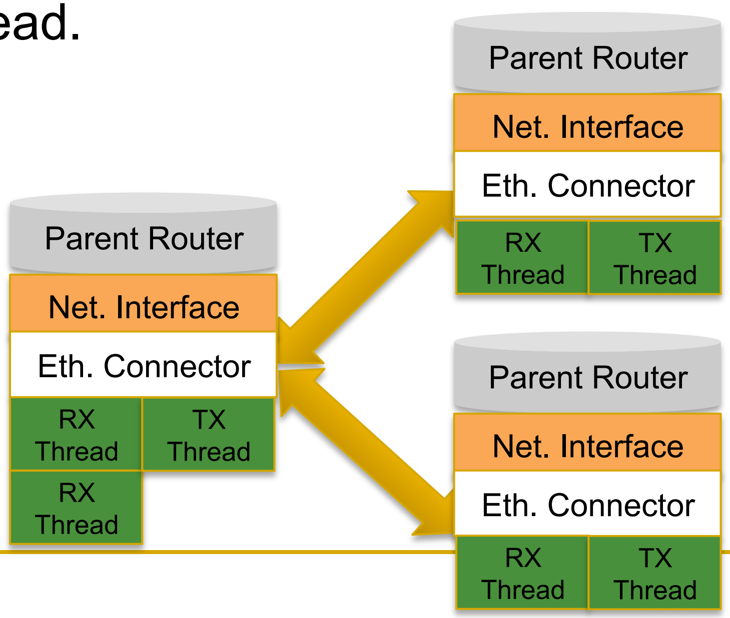
- **Inline Block**: In-line transparent block to calculate throughput
  - **Input:** Previous block
  - **Output:** Next block

- **Sink Block**: Out-of-line sink block used to calculate throughput
  - **Input:** Previous block
  - **Output:** None



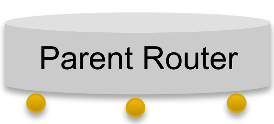
Communications

- We used Ethernet for communication between machines.
  - GR-Router was designed to work with any available communication technologies.
  - For each node there is a receive(RX) thread per child router, and a single transmit(TX) thread.

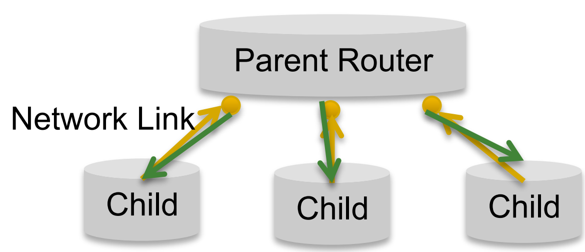


Network Interface

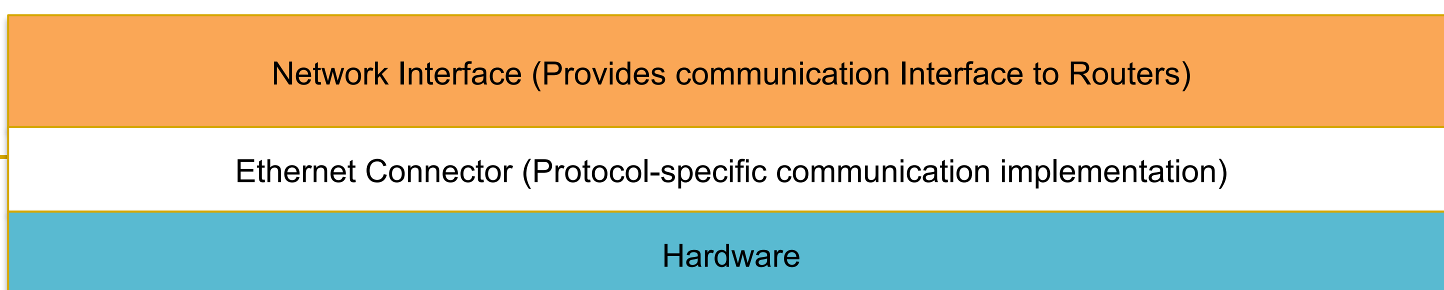
- Network Interface: Provides communication functions to Parent and Child Routers
  - **Connect**(char* hostname): connects the graph of routers
    - Each child specifies it's parent, and each parent knows the number of children it connects to.
  - **Receive**(int index, char* outbuf, int num_items): receives segments from node at index
  - **Send**(int index, char* msg, int num_items): sends message to given node
  - Uses Connector for communications; is only meant as a uniform interface for the routers to abstract away the technology-specific implementation



Wait for <number_children> connections …



After child has connected to parent, it waits for it's children to connect



Ethernet Connector

- Ethernet Connector: Ethernet-specific networking class
- Provides the following functions:
  - connect_to_parent(char* hostname, int port)
  - write_parent(char* msg, int size), read_parent(char* outbuf, int size)
  - connect_to_child(int index, int port)
  - write_child(int index, char* inbuf, int size), read_child(int index, char* outbuf, int size)
  - Stop()
- In order to use a different technology (PCIE), this connector would need to be written for that technology

Ethernet Connector (Protocol-specific communication implementation)

Hardware (Ethernet, PCIe, etc)

Example Implementation

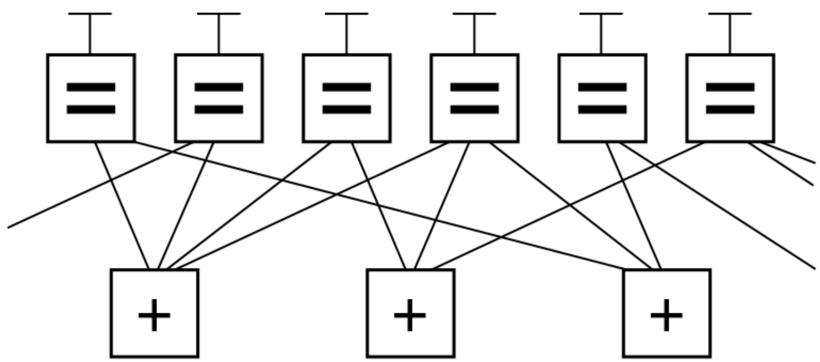
- **GR-LDPC** : Manu T S wrote an implementation of a Low-Density Parity-Check Code encoder and decoder for GSoC 2013.

- Goal: Parallelize his decoder to increase net throughput.

http://gnuradio.squarespace.com/storage/grcon13_presentations/grcon13_manuts_gsoc_ldpc.pdf

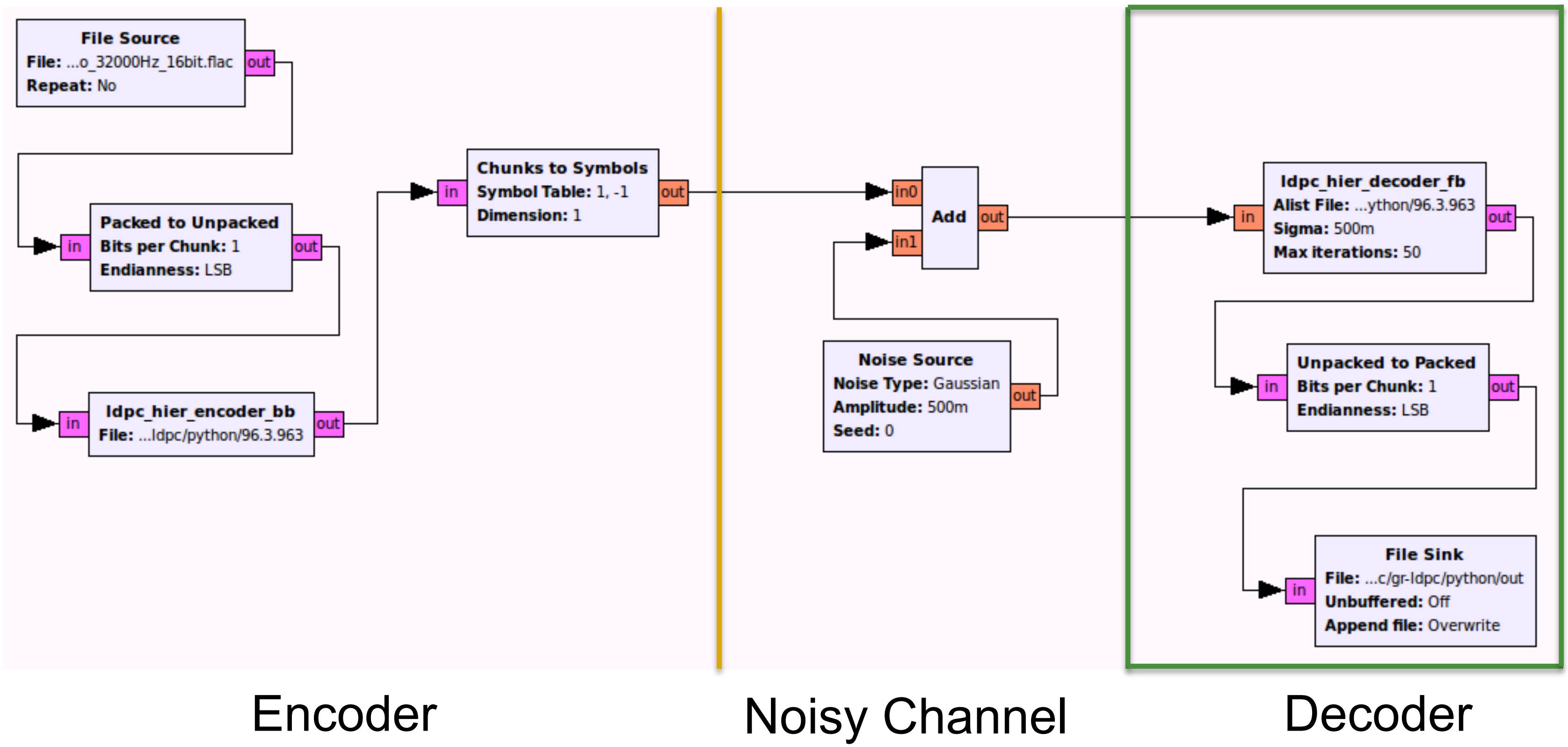
LDPC Decoding

- **LDPC**: forward error correcting code using a soft decision decoder to 'guess and check' until a valid code word is found.
  - once found, the data can be calculated or a LUT can do the translation.
- It makes these decisions independently on the n-bit code word. Therefore LDPC is data-parallelizable. Multiple code-words can be decoded in parallel.



http://en.wikipedia.org/wiki/Ldpc

Manu's LDPC Example

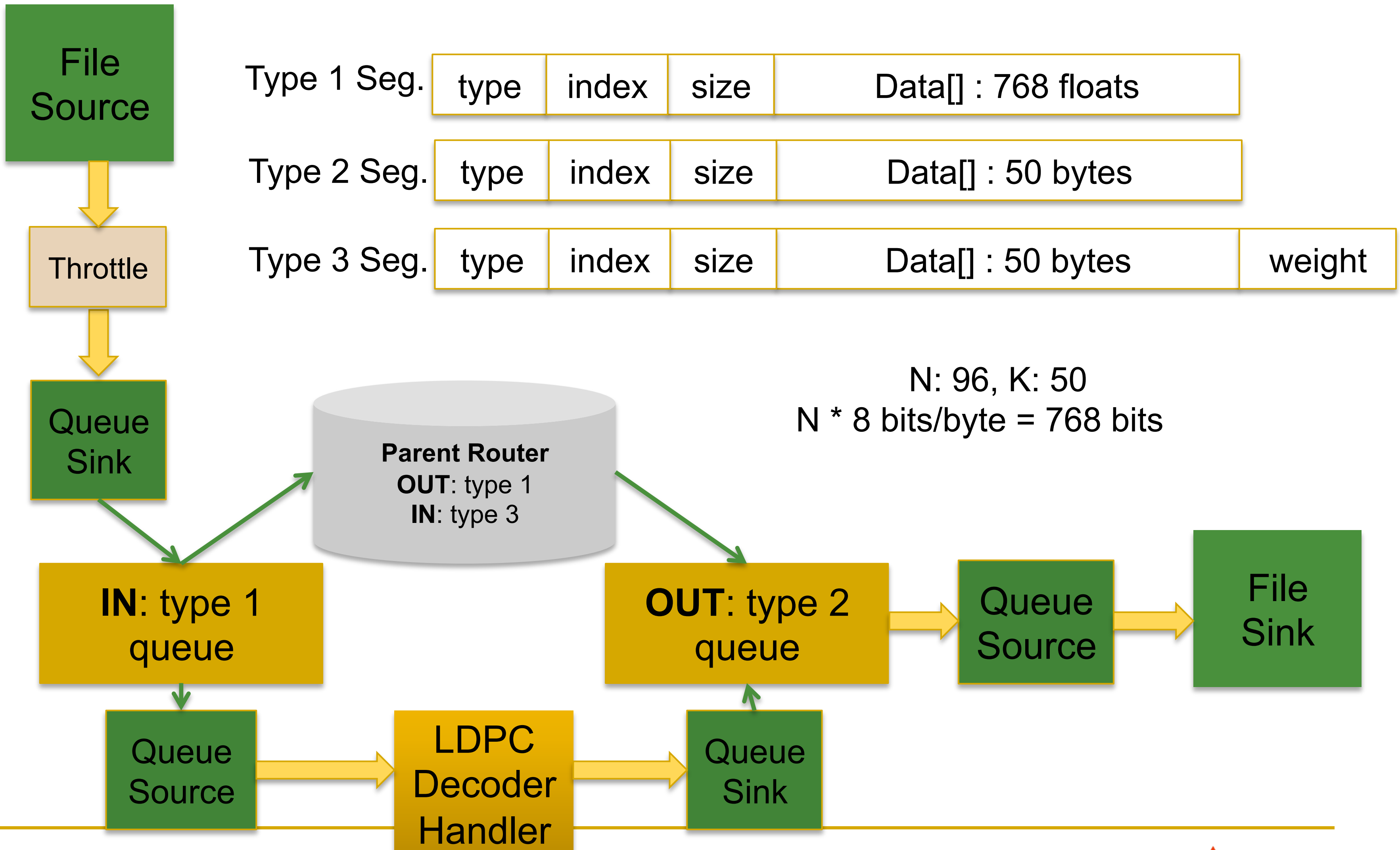


https://github.com/manuts/gr-ldpc

Parallelization Strategy

- 1. Port Manu's code to C++
- 2. Create no-noise and 0.5 pk-pk LDPC-encoded files.
- 3. Decode each of the inputs on each node and determine maximum throughput that the node can maintain without GR-Router. (base case)
- 4. Create a parent application that serves as the root of the graph.
- 5. Create a child application for all nodes that connect to the root.
- 6. Add nodes and compare throughput results.

LDPC Decoder Parent



LDPC Decoder Child

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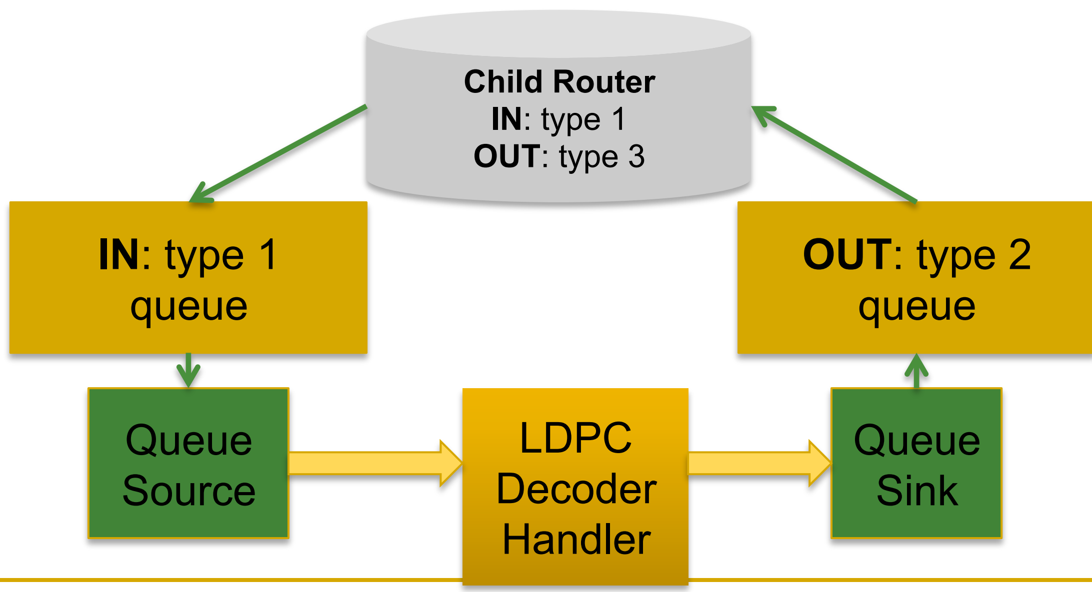

N: 96, K: 50

N * 8 bits/byte = 768 bits

Throughput Results

- Results:
  - Overhead: 20% reduced throughput on single node
  - Without noise: 20% reduced throughput when running on two nodes.
  - With 0.5 pk-pk noise: 1.8x throughput on two nodes!

- Currently running tests with 2-6 ethernet-connected machines for additional testing.

Future Work

- Continue adding features to GR-Router
  - XML integration for easy reconfiguration
    - Define segments in an xml file, and have the queue_{source, sink} and routers read them.
- Implement redundancy and fault tolerance.
- Support additional network technologies.
- Support multi-layer GNU Radio systems.
- Support inter-child communication.
- Experiment with networked low-power platforms.

http://www.iconarchive.com/show/adobe-cs4-icons-by-hopstarter/File-Adobe-Dreamweaver-XML-01-icon.html

Questions?