# ECE 6101 Final Project


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# Evaluation of NOC different Routing Protocols

### Introduction

A Network-on-Chip is an approach to designing the communication subsystems between different IP cores in a System-on-a-Chip (SOC). NoC applies networking theory and methods to on-chip communication and brings notable improvements over conventional bus and crossbar interconnections. NoC improves the scalability of SoCs, and the power efficiency of complex SoCs compared to other designs.

Traditionally, ICs have been designed with dedicated point-to-point connections, with one wire dedicated to each signal. For large designs, in particular, this has several limitations from a physical design viewpoint. The wires occupy much of the area of the chip, and in nanometer CMOS technology, interconnects dominate both performance and dynamic power dissipation, as signal propagation in wires across the chip requires multiple clock cycles.

NoC links can reduce the complexity of designing wires for predictable speed, power, noise, reliability, etc., thanks to their regular, well controlled structure. From a system design viewpoint, with the advent of multi-core processor systems, a network is a natural architectural choice. An NoC can provide separation between computation and communication, support modularity and IP reuse via standard interfaces, handle synchronization issues, serve as a platform for system test, and, hence, increase engineering productivity.

Although NoCs can borrow concepts and techniques from the well-established domain of computer networking, it is impractical to blindly reuse features of "classical" computer networks and symmetric multiprocessors. In particular, NoC switches should be small, energy-efficient, and fast. Neglecting these aspects along with proper, quantitative comparison was typical for early NoC research but nowadays they are considered in more detail. The routing algorithms should be implemented by simple logic, and the number of data buffers should be minimal. Network topology and properties may be application-specific.

### Scope of Project:

A NoC is a set of interconnected switches, with IP cores connected to these switches. Four main components compose a switch: a router, to define a path between input and output switch ports; an arbiter, to grant access to a given port when multiple input requests arrive in parallel; buffers, to store intermediate data, and a flow control module to regulate the data transfer to the next switch. The goal of this work is to compare the performance of four routing algorithms for mesh based packet switching

NoCs. The simulations will be performed in NOXIM, an NOC simulator designed at the University of Catania.

In this project, we aim to study different Routing Protocols and Selection Strategies present in the NOC Paradigm. Routing algorithms define the path taken by a packet between source and target switches. Routing algorithms can be classified according to the three different criteria: (i) where he routing decisions are taken; (ii) how a path is defined, and (iii) the path length. According to where routing decisions are taken, it is possible to classify the routing in source and distributed routing. Depending how a path is defined, routing can be classified as deterministic or adaptive. Regarding the path length criterion, routing can be minimal or nonminimal. In this report, we will be exploring four routing protocols:

- XY (deterministic)
- West first (partially adaptive)
- North-last (partially adaptive)
- Negative-first. (partially adaptive)
- Odd-even(partially adaptive)
- Fully-Adaptive

A selection strategy is used to choose the channel that will allow the packet to be routed to its destination along a path that is as free as possible of congested nodes. This is different from Routing protocols. Routing protocols define the overall path from the source to the destination node. In selection strategy, we define the manner in which each node decides the next hop (very similar to forwarding techniques in classical networks). In the project we will be analyzing 3 different selection strategies:

- Random
- Buffer-level
- Neighbours-on-path

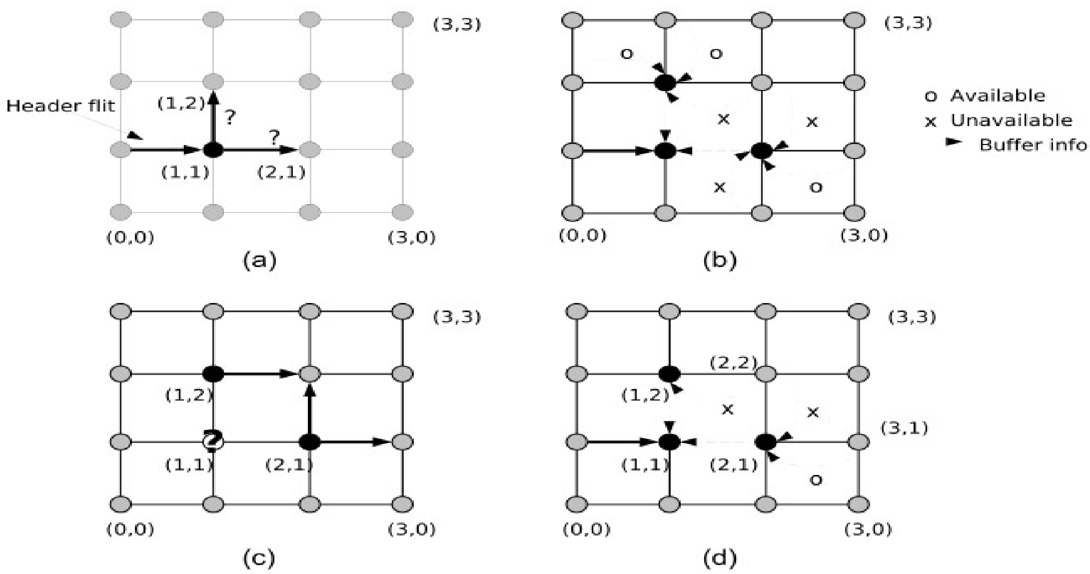
Random Selection:

- Outgoing path of a packet is selected based on probability calculation
- No network information is needed
- Route is typically not least cost nor minimum hop
- Network traffic not taken into consideration, may take a while to reach final destination

Buffer-level based Selection:

- Outgoing path of a packet is selected based on buffer-levels in the network
- Network information is used to obtain better performance than random selection.

Neighbors – on – path (nop) Selection:




(a) Node (1, 1) has to choose between two possible candidates.

(b) Nodes (2, 1) and (1, 2) receive information about buffer availability from their neighbors.

(c) Node (1, 1) figure out which output channels would return routing function applied at nodes (1, 2) and (2, 1).

(d) Node (1, 1) exploit buffer availability of its Neighbors- on-Path.

**NOXIM (NOC Simulator)**

The Noxim simulator is developed using SystemC, a system description language based on C++, and it can be downloaded from SourceForge under GPL license terms.
Noxim has a command line interface for defining several parameters of a NoC. In particular the user can customize the network size, buffer size, packet size distribution, routing algorithm, selection strategy, packet injection rate, traffic time distribution, traffic pattern, hot-spot traffic distribution.
The simulator allows NoC evaluation in terms of throughput, delay and power consumption. This information is delivered to the user both in terms of average and per-communication results.
In detail, the user is allowed to collect different evaluation metrics including the total number of received packets/flits, global average throughput, max/min global delay, total energy consumption, per-communications delay/throughput/energy etc.

The Simulator has a very simple definition for various abstractions of the network, defined as structs and classes. For example, NoximCoord class takes in the X and Y co-ordinates of the mesh it is simulating. Also, the packet structure is defined as follows:

*struct NoximPacket* {
    *int src_id;*
    *int dst_id;*

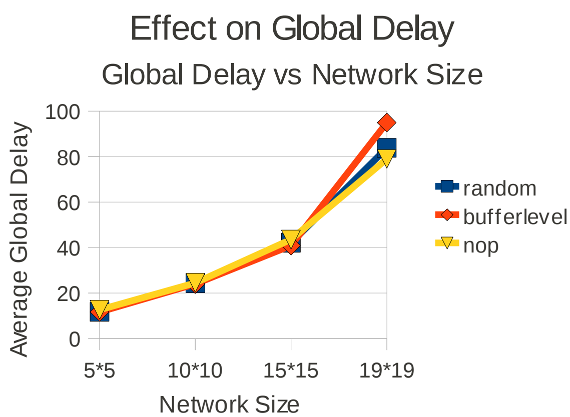
```
        double timestamp; // SC timestamp at packet generation
        int size;
        int flit_left; // Number of remaining flits inside the packet

        // Constructors
        NoximPacket() { }
        NoximPacket(const int s, const int d, const double ts, const int sz) {
        make(s, d, ts, sz);
        }

        void make(const int s, const int d, const double ts, const int sz) {
        src_id = s;
        dst_id = d;
        timestamp = ts;
        size = sz;
        flit_left = sz;
        }
};
```

Similar C/C++ abstractions are used to represent flits and routes as well. Using this simulator, we have performed many analysis. We will be presenting the results and analyzing them below.

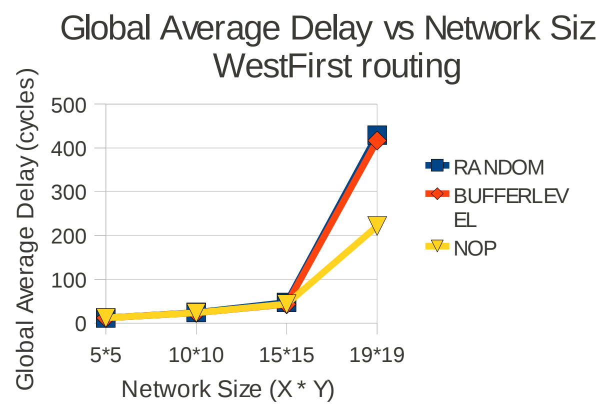
# Observations and Analysis:

## 1) Effect on Global Delay for varying selection strategies

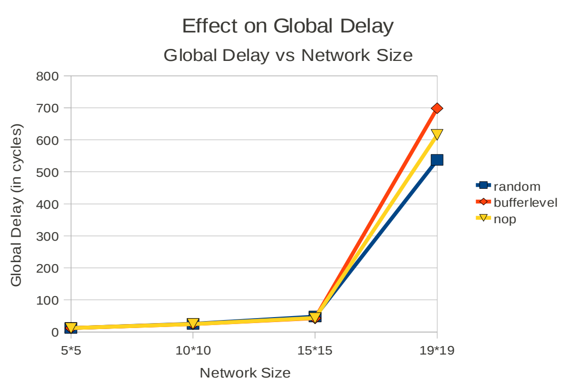
-Observations



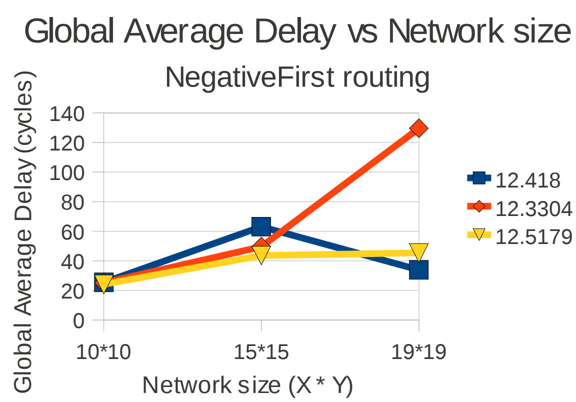

XY Routing Algorithm



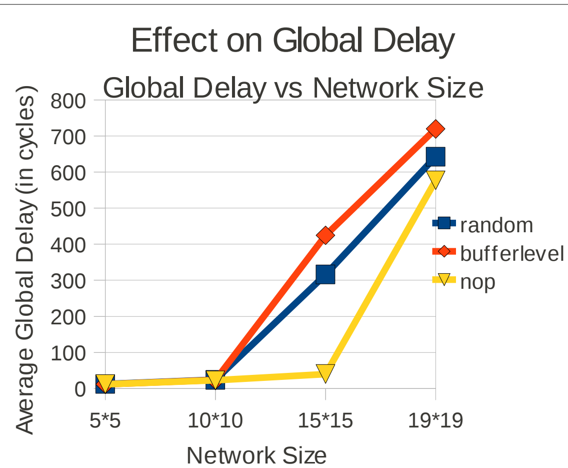

WestFirst Routing



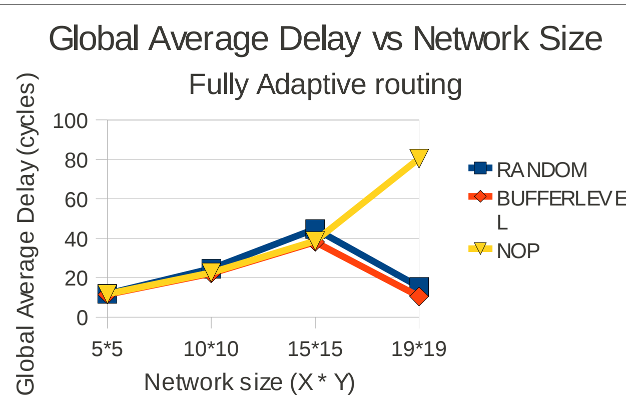

NorthLast Routing Algorithm




NegativeFirst Routing Algorithm




Odd-Even Routing Protocol




Fully-Adaptive Routing

-Analysis

- Global Delay, in general, increases with the size of the network. This is because of the time required by the packet to reach the destination from the source increases with an increase in the number of nodes that it has to route through.

- WestFirst and NorthLast routing protocols show very less Global delay for lower size of the mesh while the Global delay increases significantly for larger mesh (19 x 19)

- For a very large networksize, NorthLast and Odd-Even routing protocols have a very high routing delay

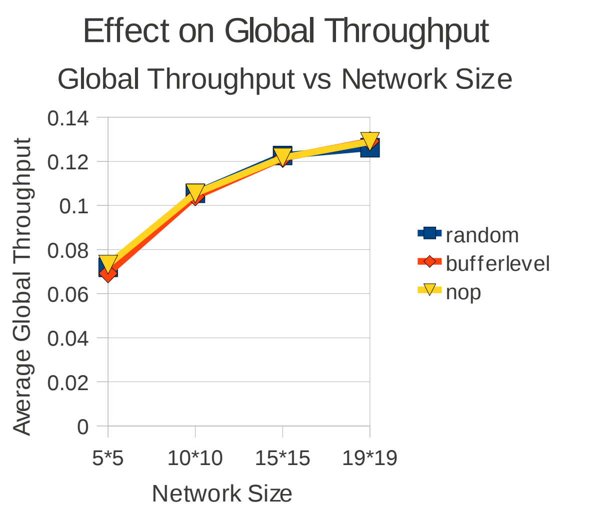
- In Fully-Adaptive routing protocol, we see that at very large network size, the delay is lesser for Random and buffer-level based selection strategies. This is because of the fact that NOP strategy puts certain restrictions on the selection of the neighbor to be used for routing

- In XY routing and Northlast routing protocols, the global delay seems to be independent of the selection strategy for any number of nodes

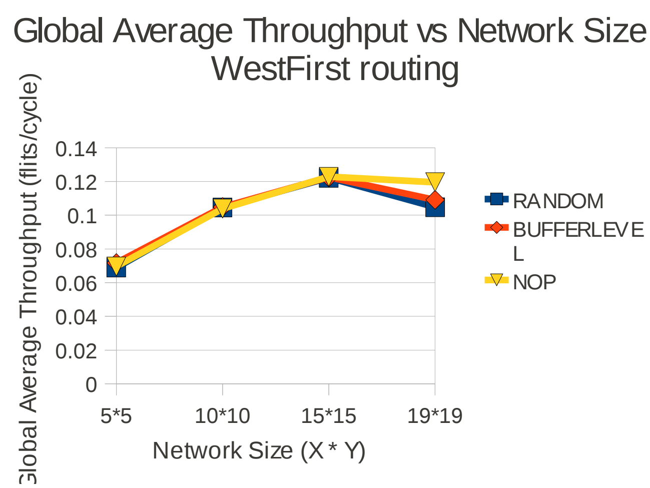
- Buffer-level selection strategy gives the highest global delay in all routing protocols for all network sizes, except for fully adaptive routing. This is because of the limitations put on selecting the next node for a packet based on the size and empty space available in the buffer.

## 2) Effect on throughput for varying selection strategies

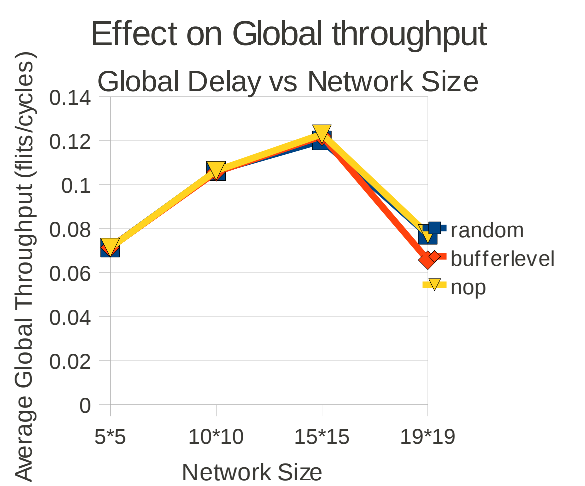
-Observations



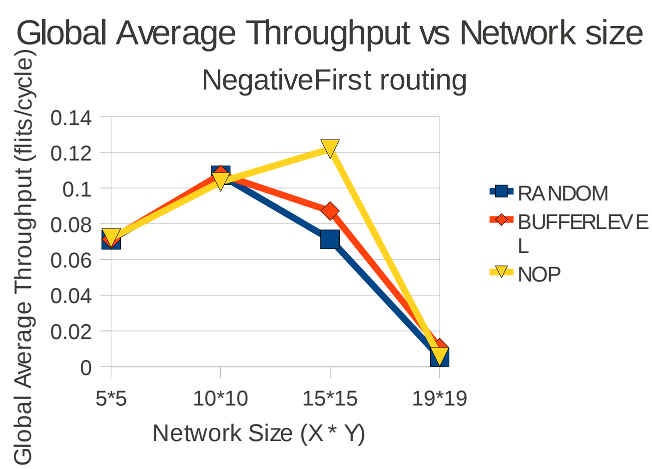

XY Routing Algorithm



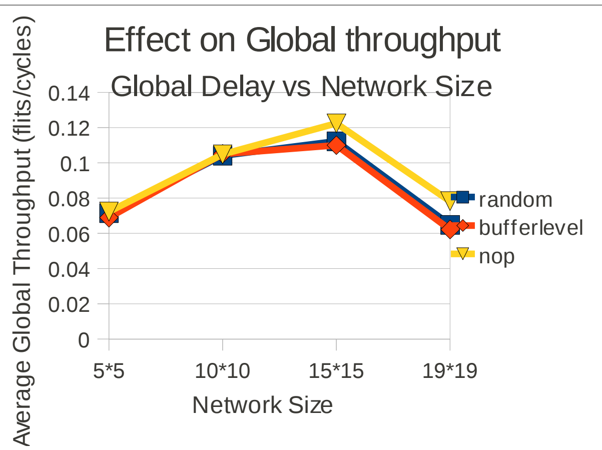

WestFirst Routing



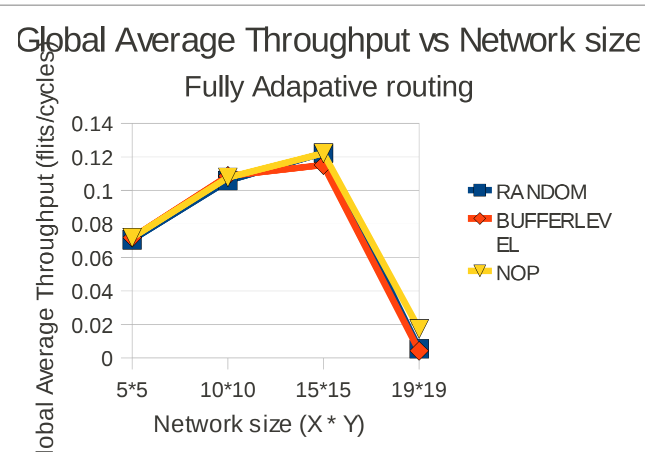

NorthLast Routing Algorithm




NegativeFirst Routing Algorithm




Odd-Even Routing Protocol




Fully-Adaptive Routing

-Analysis:

- The throughput shows an uniform trend for all the routing protocols. The throughput seems to be increasing for lower number of nodes but it starts decreasing after a certain size of the network (most prominently at 10*10 and 15*15). This is because of the increase in traffic in the network for larger number of nodes, contributed by the flits which have still not reached their intended destination. This is also corroborated by the increase in global delay which indicates that more and more packets have not reached their destinations

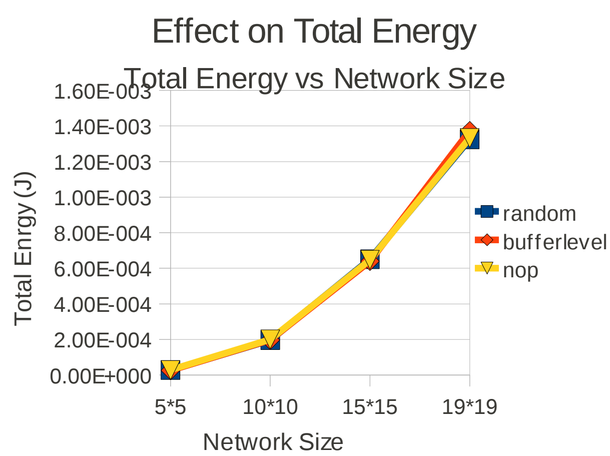
- An interesting observation is that the throughput is very low for NegativeFirst and Fully-Adaptive routing algorithms for a very large mesh size. This could be due to the possibility of deadlocks in these routing algorithms for larger mesh sizes

- The maximum throughput received is 0.12 flits/cycles for all the protocols

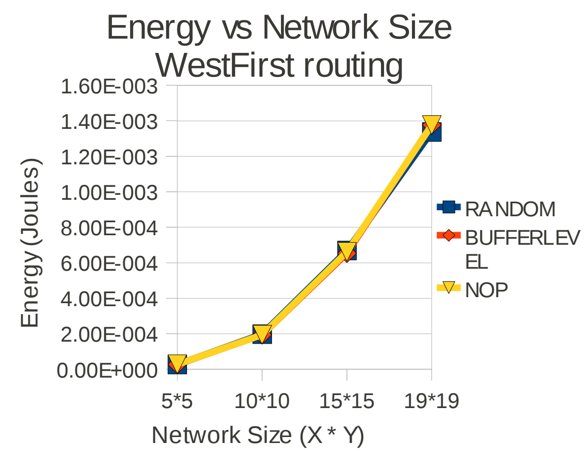
- Selection algorithms do not seem to be making any difference on throughput for all routing protocols

### 3) Comparison of different routing protocols with energy consumption

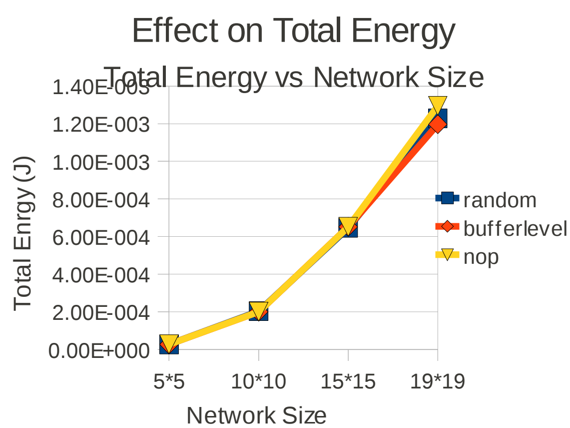
-Observations:



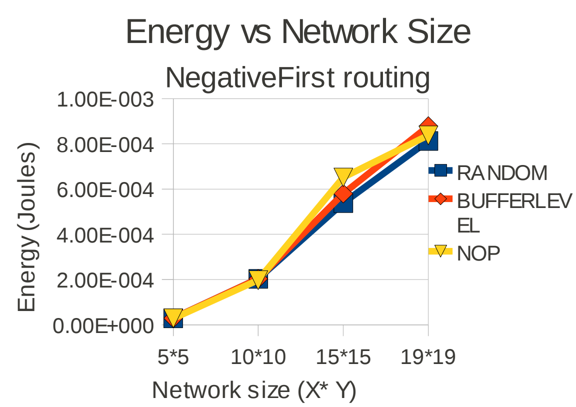

XY Routing Protocol



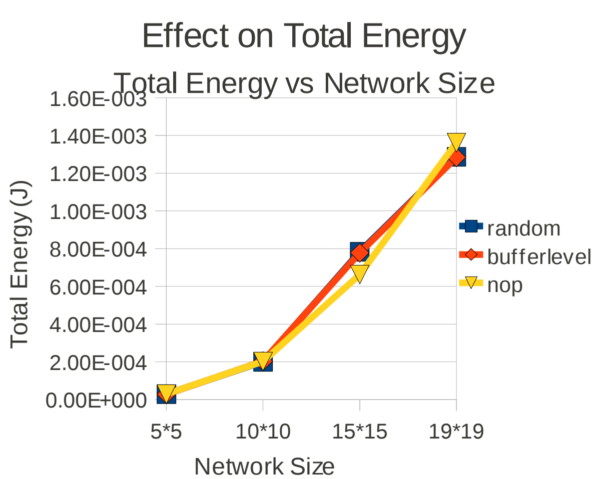

WestFirst Routing



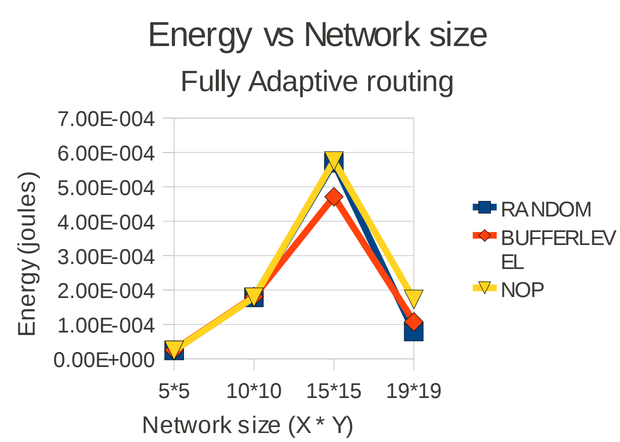

NorthLast Routing Algorithm




NegativeFirst Routing Algorithm




Odd-Even Routing Protocol



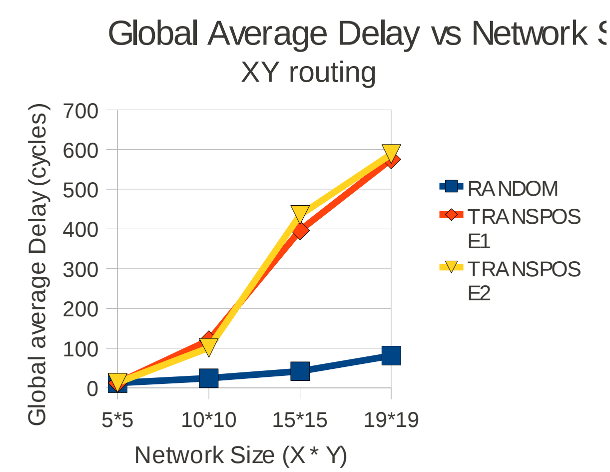

Fully-Adaptive Routing

-Analysis:

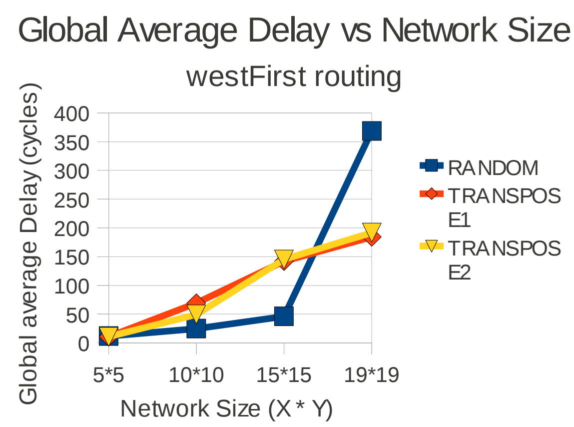
- The energy consumed increases with the increase in number of nodes for all protocols except Fully-Adaptive
- Fully-Adaptive routing consumes the least amount of energy for larger network sizes
- There is no change observed in energy consumption with any change in selection strategy
- North-last and Odd-even routing protocols show a steeper rise in energy for all selection strategies as compared to other protocols

## 4) Comparison of different routing protocols with Global Delay for varying Traffic Type

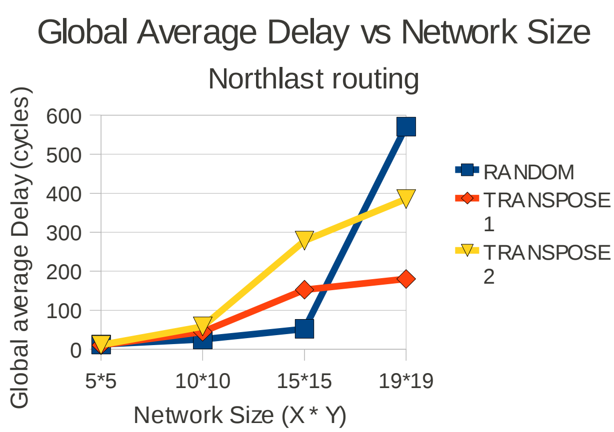
-Observations



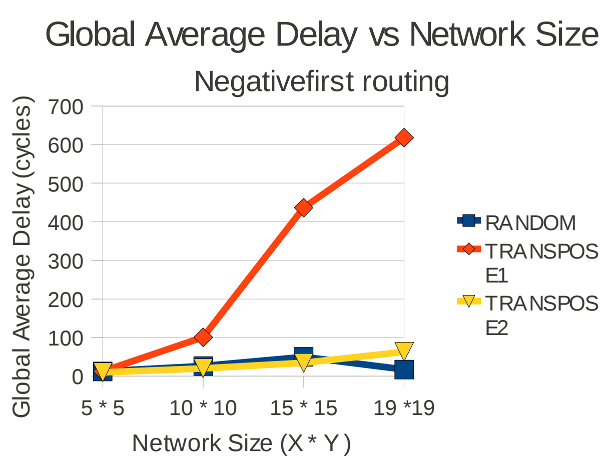

XY Routing Algorithm



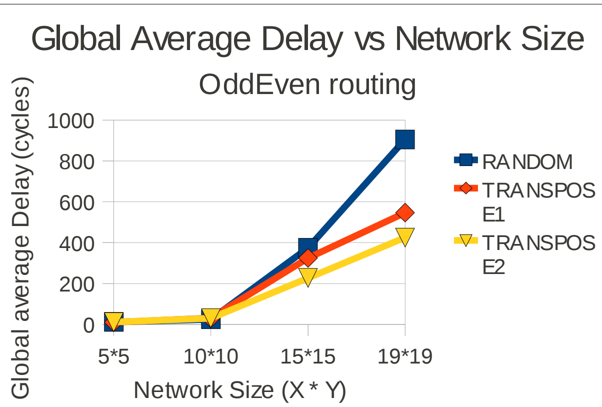

WestFirst Routing



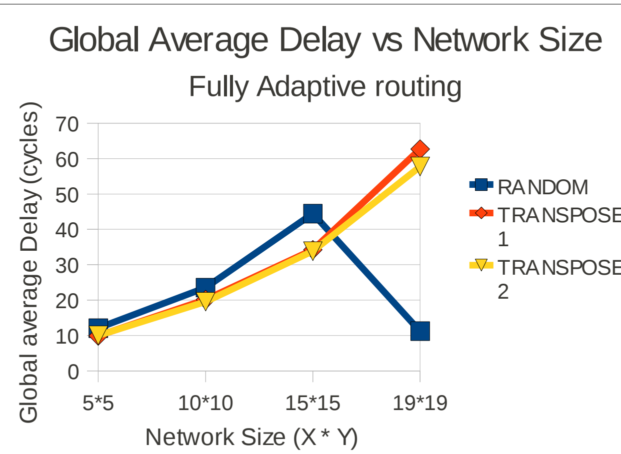

NorthLast Routing Algorithm




NegativeFirst Routing Algorithm




Odd-Even Routing Protocol




Fully-Adaptive Routing

-Analysis

- For different traffic generation mechanisms, we see that the global delay increases in general

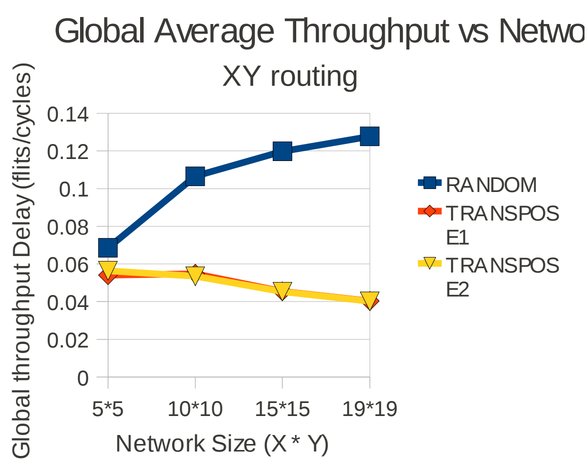
- Random traffic generation mechanisms means that all the different routing protocols show random behavior in terms of delay

- For Negative First routing, Transpose1 traffic generation mechanism shows an unusually high global delay for higher number of nodes

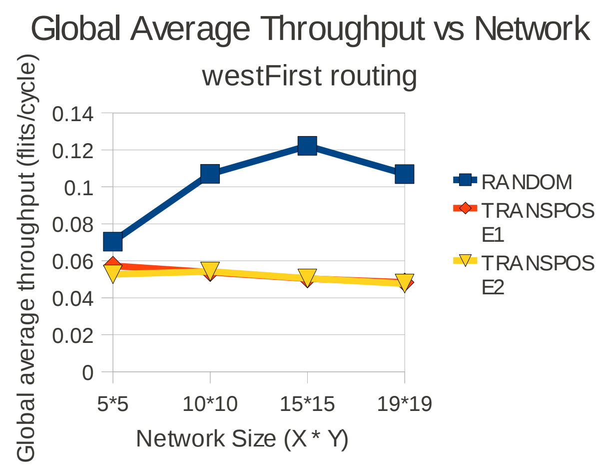
- Apart from that, transpose1 and transpose2 traffic generation mechanisms have almost the same Global Delay behavior

**<u>5) Comparison of different routing protocols with Throughput for varying traffic type</u>**

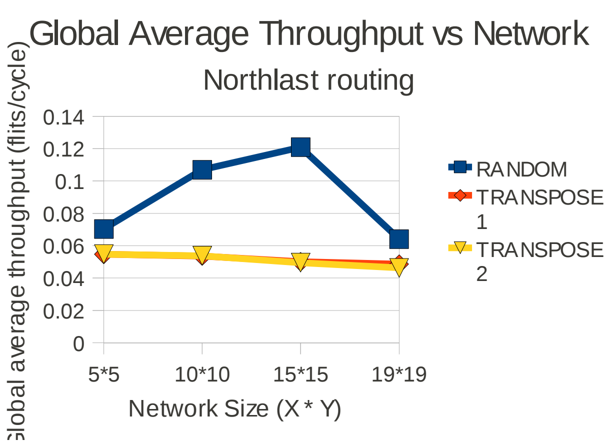
-Observation



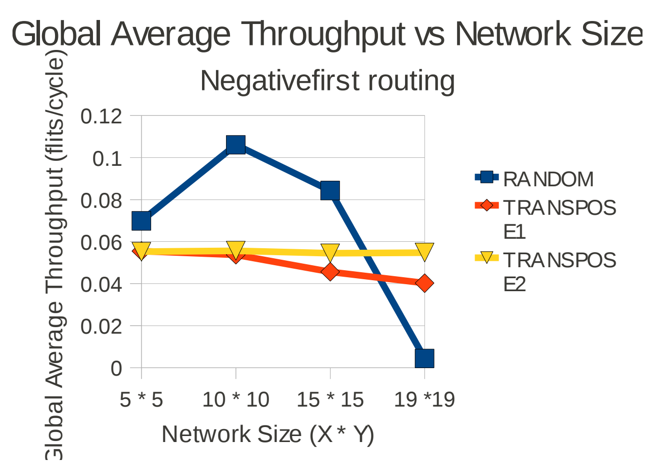

XY Routing Algorithm



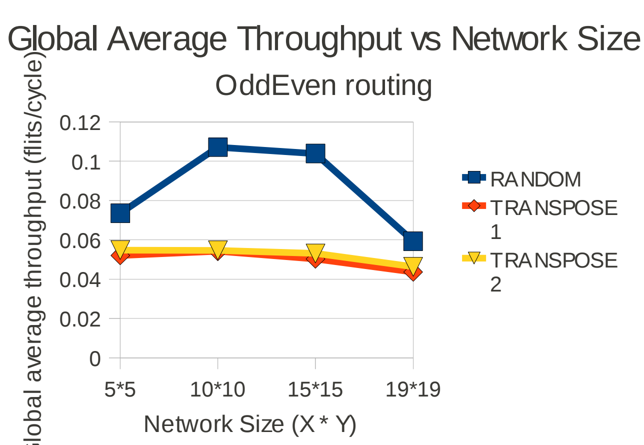

WestFirst Routing



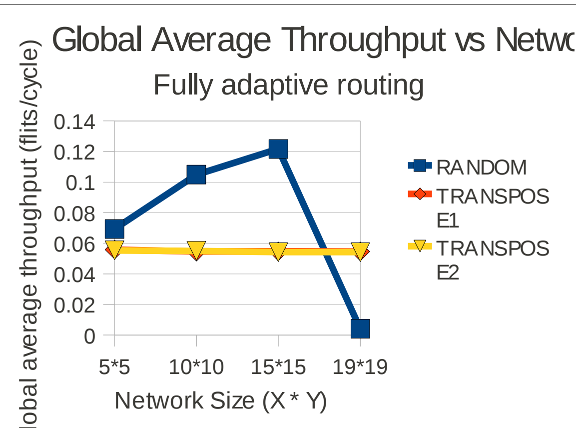

NorthLast Routing Algorithm




NegativeFirst Routing Algorithm




Odd-Even Routing Protocol




Fully-Adaptive Routing

-Analysis:

- On an average, random traffic generation mechanism gives a higher throughput as compared to the other traffic generation mechanisms

- For all routing protocols, with increasing network size, the random traffic generation mechanism initially increases the throughput while it start decreasing later

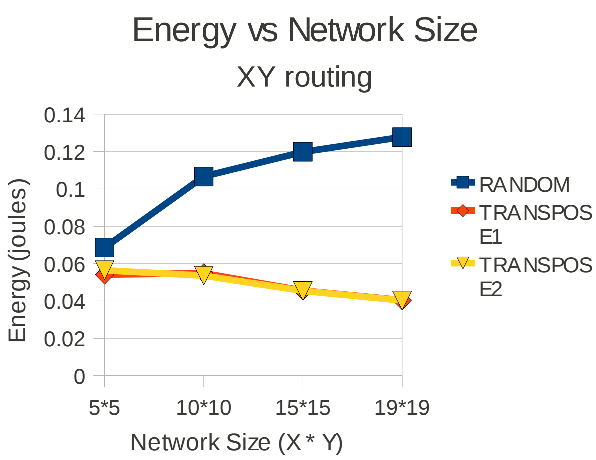
- In all the routing protocols, the effect of throughput is almost the same for both Transpose1 and Transpose2 traffic generation mechanisms

- For transpose1 and transpose2 traffic generation mechanism, there is no change in throughput with increasing network size

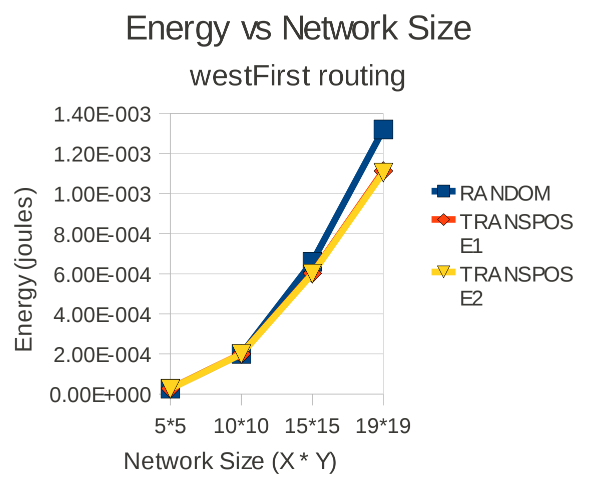
- The throughput is very low for a very high network size in negative first routing and Fully adaptive routing protocols due to possible deadlock conditions arising due to larger network size

## 6) Comparison of different routing protocols with Energy for varying traffic type

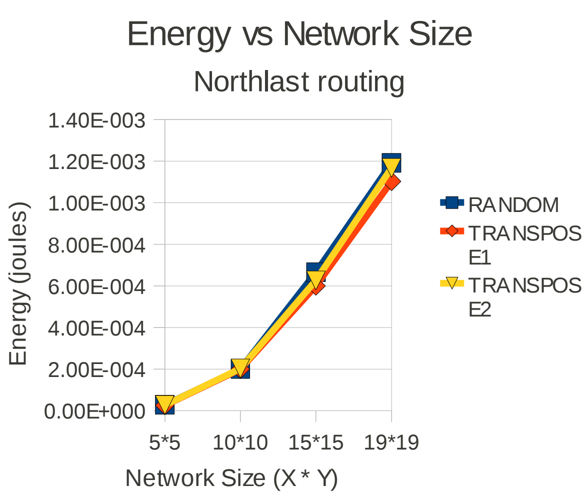
-Observation



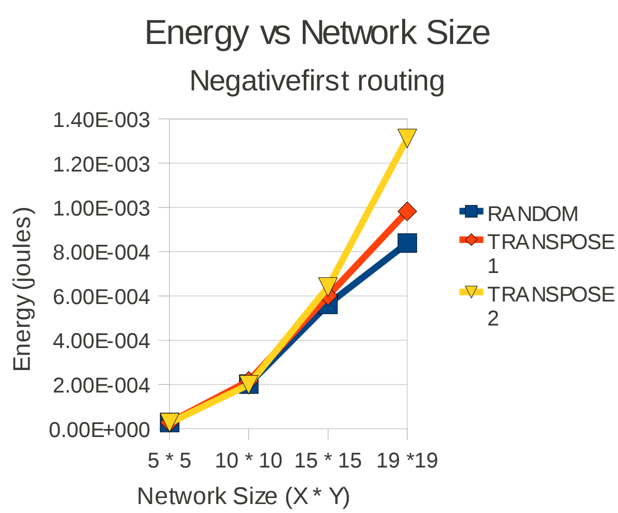

XY Routing Algorithm



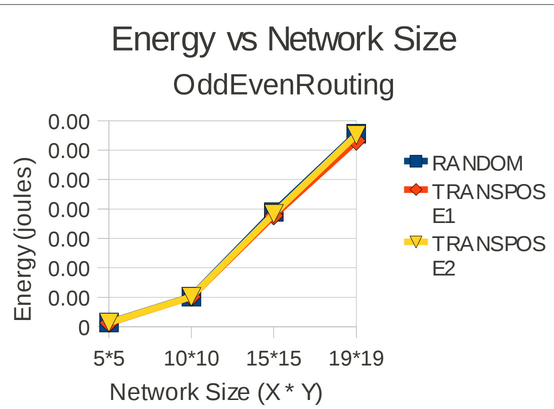

WestFirst Routing



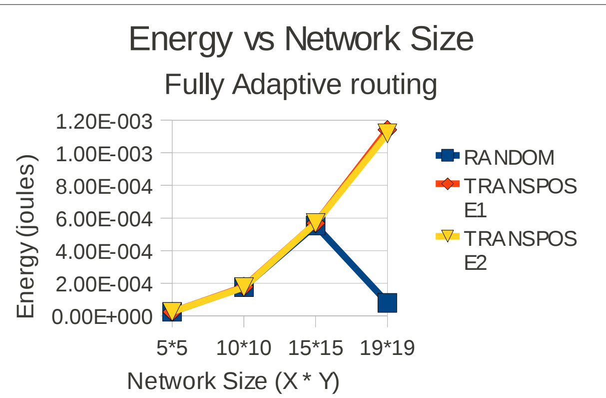

NorthLast Routing Algorithm




NegativeFirst Routing Algorithm




Odd-Even Routing Protocol




Fully-Adaptive Routing Protocol

-Analysis:

- In XY routing, random traffic generation consumes almost double the energy as compared to the other traffic generation mechanisms

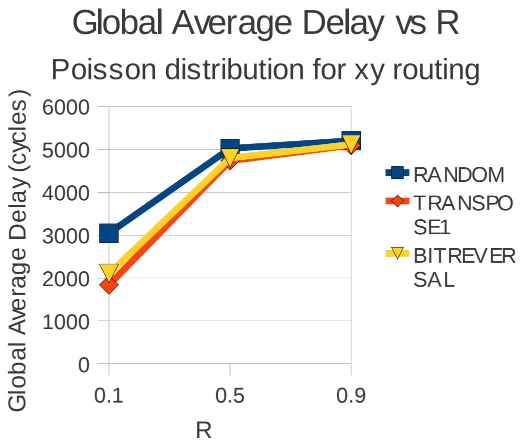
- The other routing protocols are independent of the traffic generation mechanism (except fully adaptive protocol).

- Highest amount of energy is consumed by random traffic generation in XY protocol

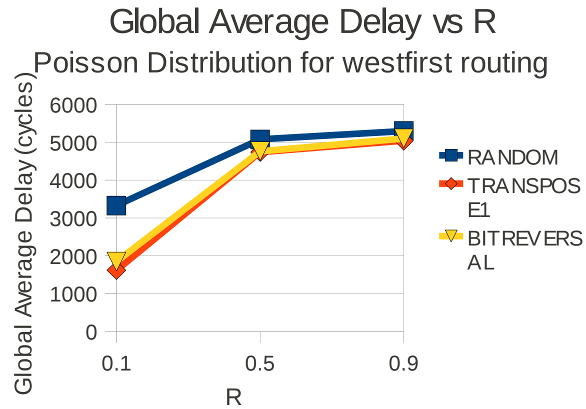
- There is very low energy consumption in Fully adaptive routing due to possible deadlock conditions at very high network size

## 7) Effect of variation in value of R in Poisson Distribution for with Global Delay

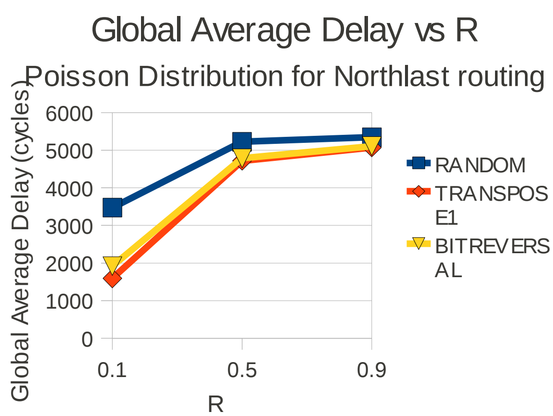
-Observation:



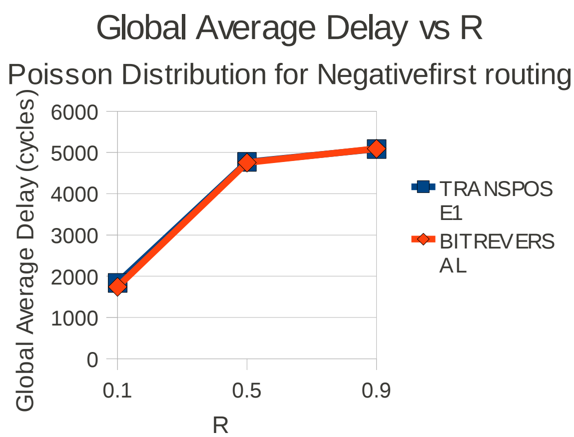

XY Routing Algorithm



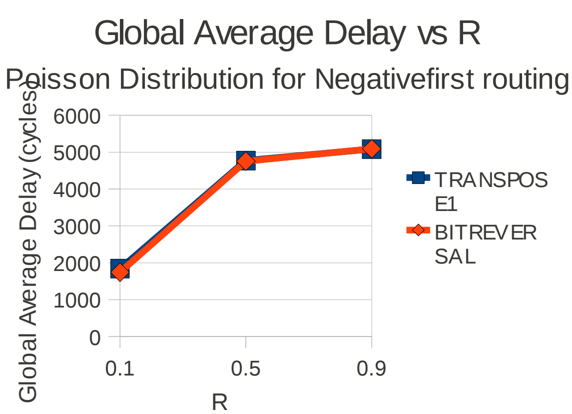

WestFirst Routing



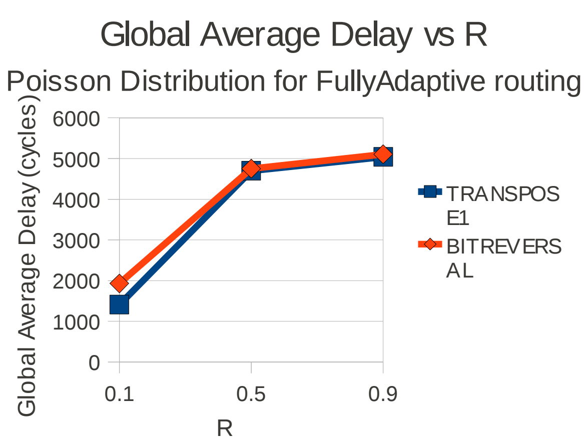

NorthLast Routing Algorithm




NegativeFirst Routing Algorithm




Odd-Even Routing Protocol




Fully-Adaptive Routing Protocol

-Analysis:

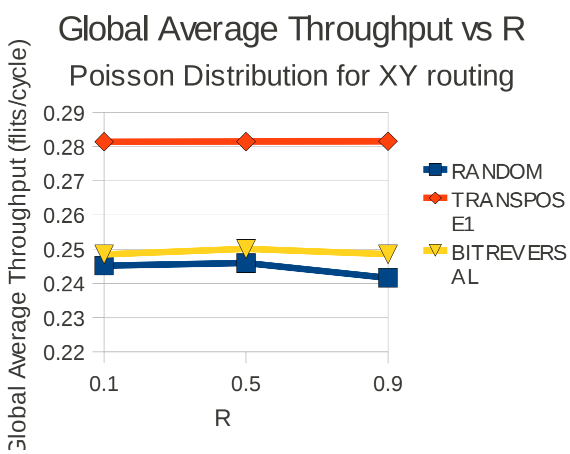
- As the Packet Injection Rate increases, the Global average delay increases

- But some routing strategies & selection strategies perform better than others at low loads. For example, for xy routing, transpose1 selection strategy performs slightly better than bit reversal & considerably better than random selection strategy. Similar results can be observed for westfirst, northlast, negativefirst, oddeven & fully-adaptive. Hence, transpose1 performs the best irrespective of routing strategy.

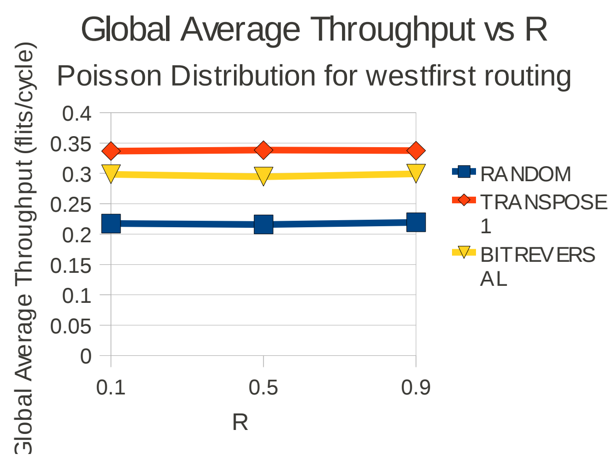
- Fully-Adaptive routing with transpose1 selection performs the best among all routing strategies as it has minimum delay.

**8) Effect of variation in value of R in Poisson Distribution for with Global Throughput**

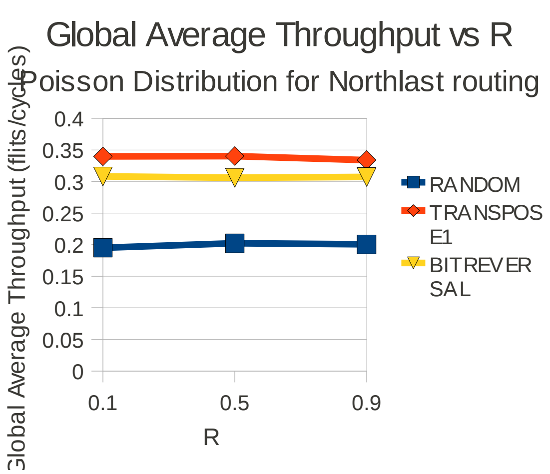
-Observation:



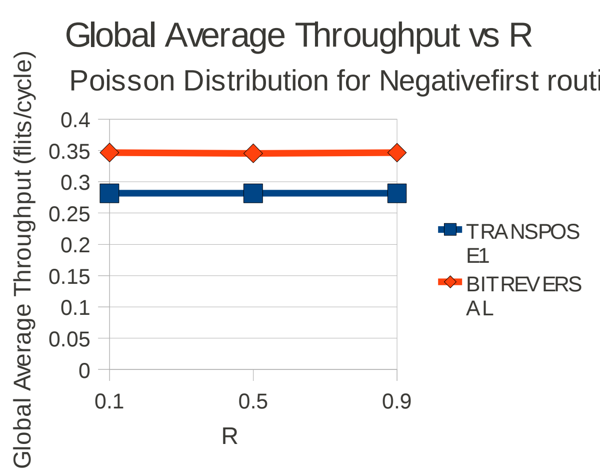

XY Routing Algorithm



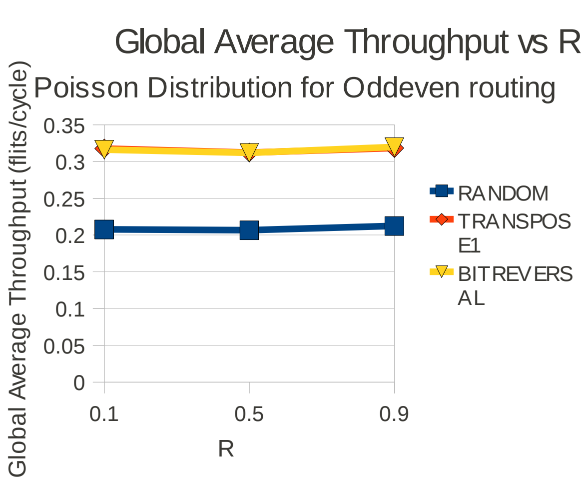

WestFirst Routing



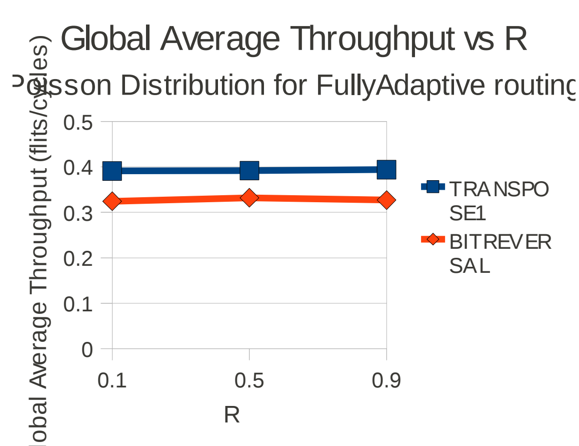

NorthLast Routing Algorithm




NegativeFirst Routing Algorithm




Odd-Even Routing Protocol




Fully-Adaptive Routing Protocol

-Analysis:

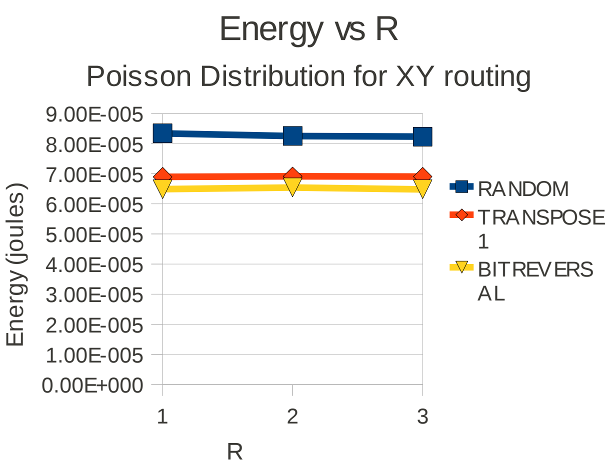
- As Packet Injection Rate (PIR) increases, it is expected that the Global average throughput should decrease. But, in most routing strategies & selection strategies, the throughput remains more or less constant. Only in xy routing with random selection strategy the throughput reduces as PIR increases

- It is observed that Fully-Adaptive routing with transpose1 selection has maximum throughput among all routing strategies. Transpose1 selection strategy performs best for all routing strategies & random selection strategy performs worst for all routing strategies

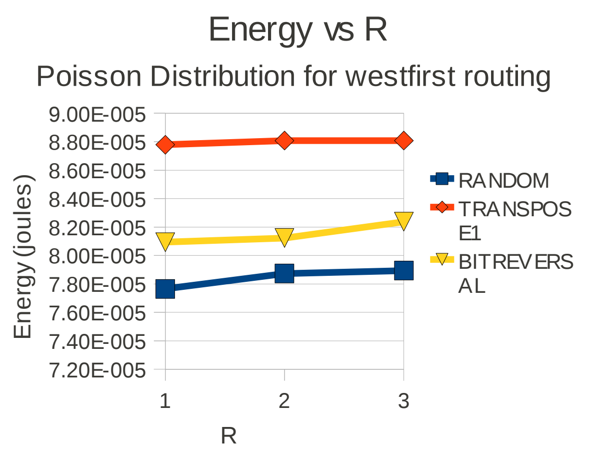
- For xy routing, bit reversal & random selection strategies perform considerably worse than transpose1. For WestFirst & North-last routing strategies, bit reversal performs significantly better than random but still worse than transpose1.

**9) Effect of variation in value of R in Poisson Distribution for with Energy**

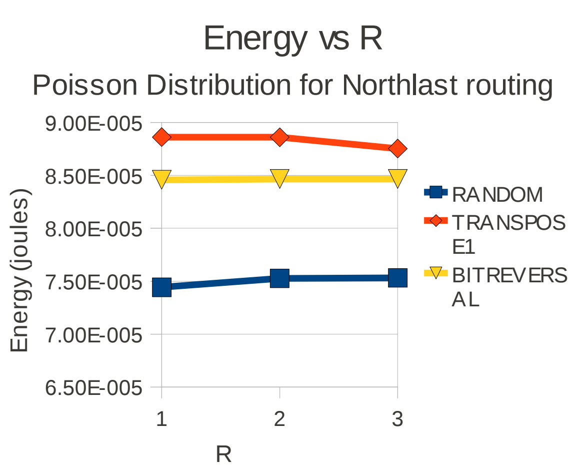
-Observation:



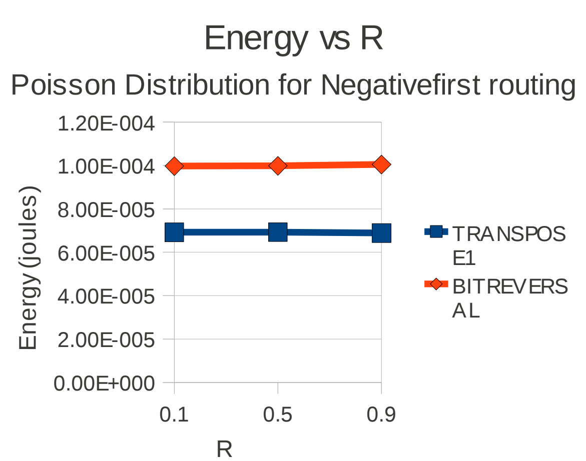

XY Routing Algorithm



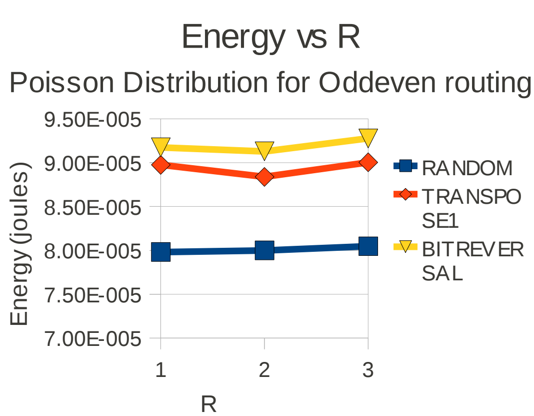

WestFirst Routing



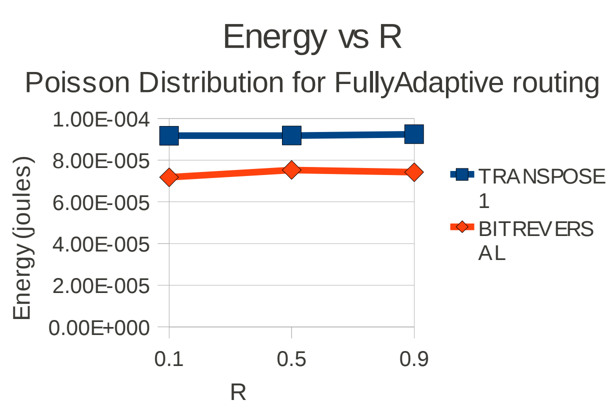

NorthLast Routing Algorithm




NegativeFirst Routing Algorithm




Odd-Even Routing Protocol




Fully-Adaptive Routing Protocol

-Analysis:

- Random selection strategy requires minimum energy for almost all routing strategies except xy, where it requires maximum energy.

- Random selection strategy doesn't perform well with respect to Global average delay & throughput but it requires minimum energy

- Transpose1 requires maximum energy in all routing strategies except OddEven. But, transpose1 performs best

- Fully-Adaptive routing with transpose1 which performs best among all strategies requires maximum energy.

## Conclusion:

Thus, there is a trade-off between performance and energy. The selection of routing & selection strategies is application-specific. If an application requires best performance in terms of delay & throughput, energy requirements may be very high. But, if the application is energy constrained, then it may have to compromise on delay & throughput. This report stands as an initial analysis for the different routing protocols. This study can be used for determining the most appropriate routing algorithm and selection strategies based on traffic generation techniques for various applications.