Modeling NoC Traffic Locality and Energy Consumption with Rent's Communication Probability Distribution

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Outline

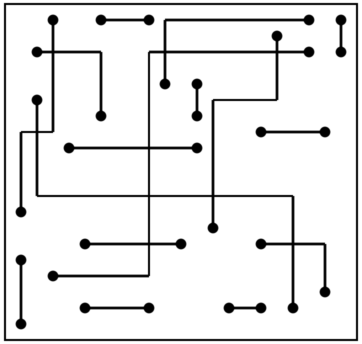
1) Communication Probability Distribution (CPD)

2) Rent’s rule-based synthetic traffic patterns

3) Modeling energy consumption using the CPD

Communication Locality in VLSI

- Conventional VLSI Design
  - Dedicated wires
  - Wires are routed to minimize communication distances (circuit placement)
  - Rent’s rule-based wire length distribution



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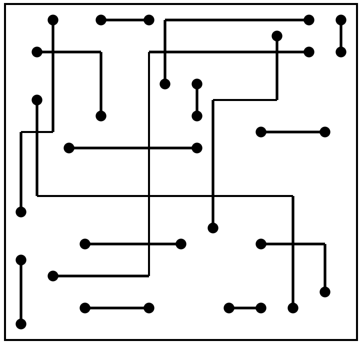
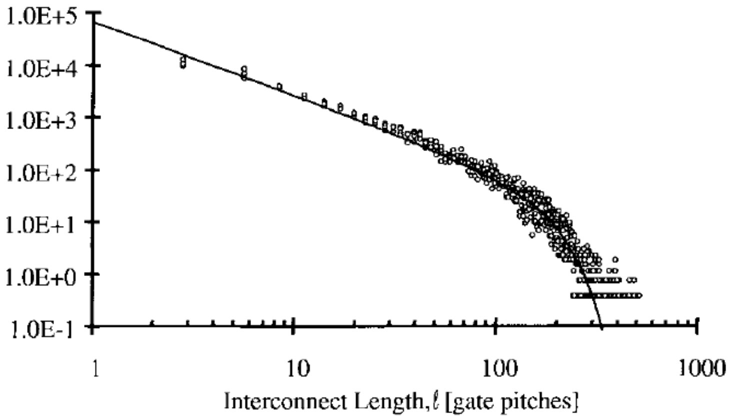
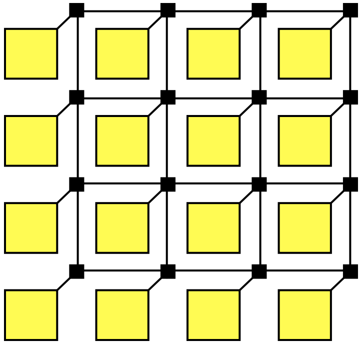




(Davis *et al.*, 1998)

Communication Locality in NoC

- Network on chip
  - Shared communication medium
  - Packets are routed to minimize communication distances (application mapping)
  - Communication probability distribution (CPD)



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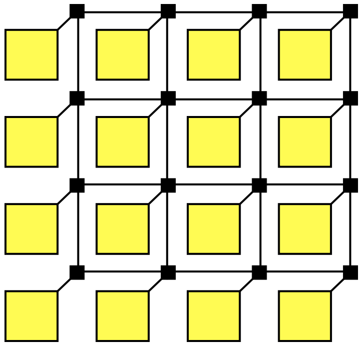

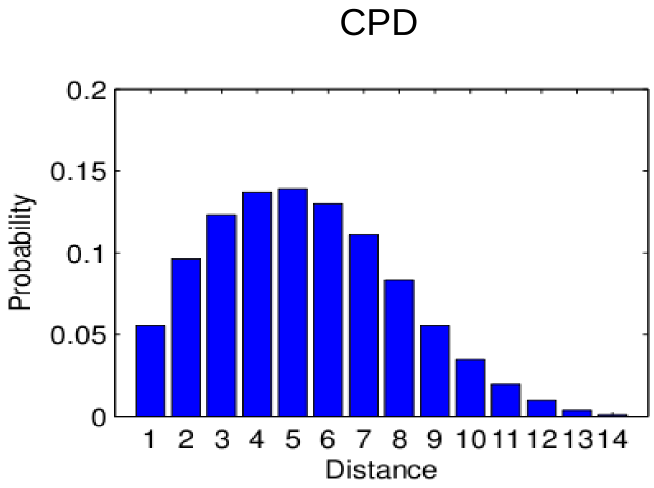

Rent's rule for parallel programs

- Bandwidth version of Rent's rule (Greenfield *et al.*, 2007)

$$B = b N^{p}$$

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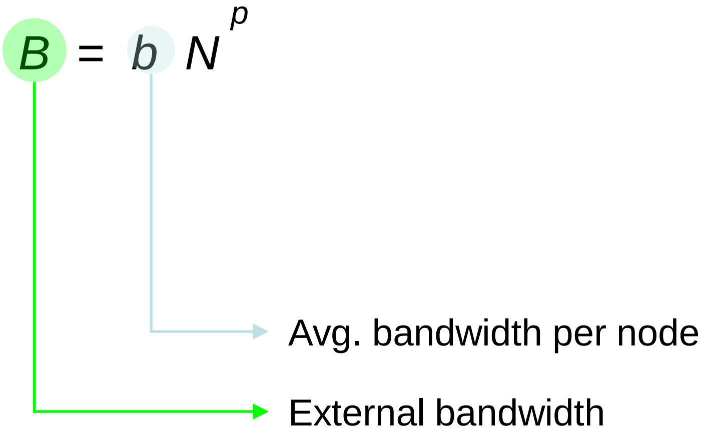

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Avg. bandwidth per node

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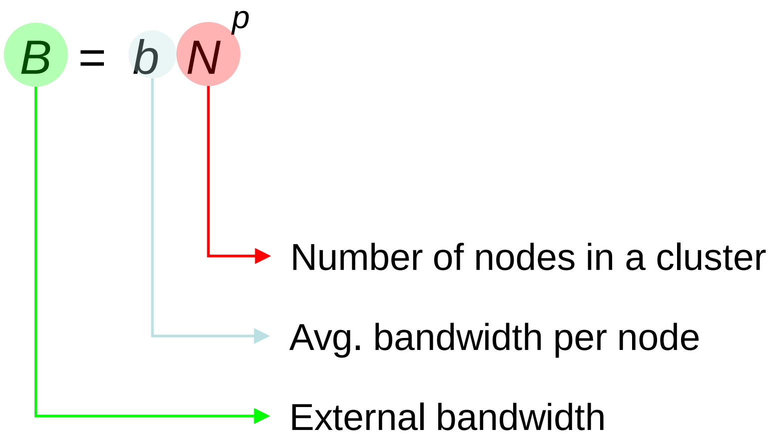

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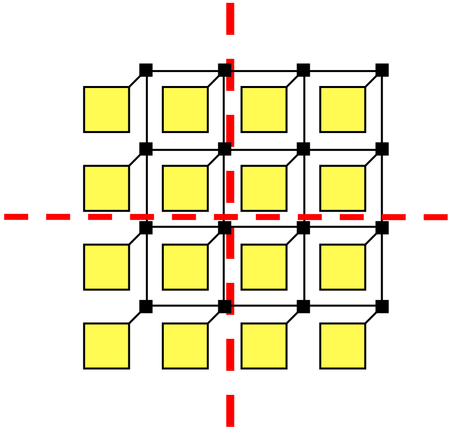

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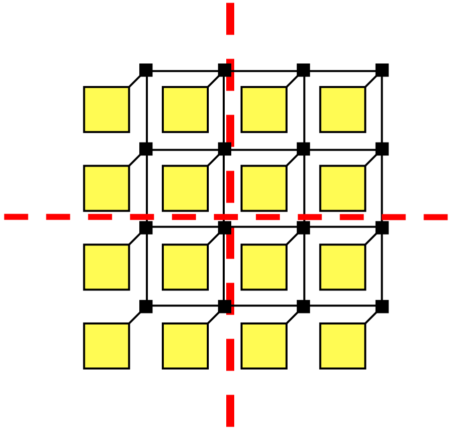
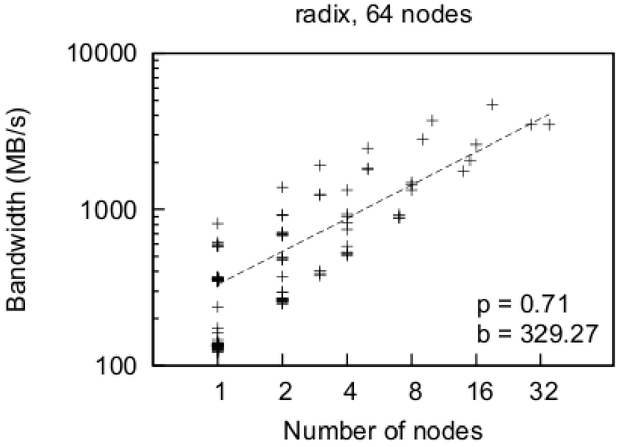
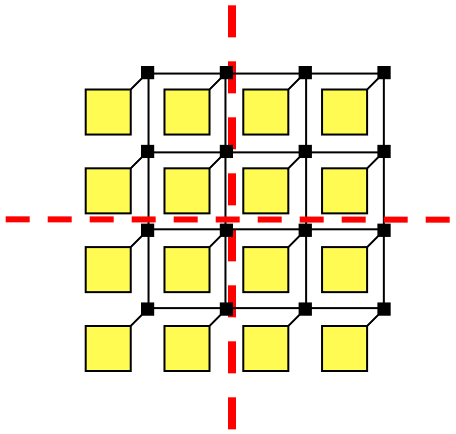


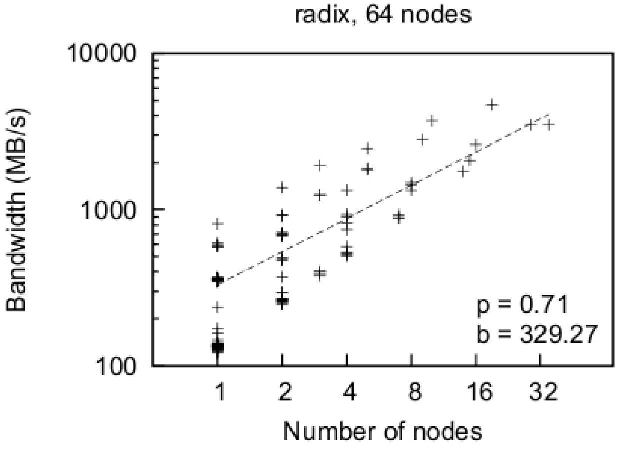


Rent’s rule for parallel programs

- Measuring Rent’s rule in CMP (Heirman *et al*., 2008)
  - Apply a hierarchical partitioning algorithm
  - All 13 benchmark applications followed Rent’s rule with

    $0.55 \leq p \leq 0.75$





Generating synthetic workloads

- Can we generate synthetic traffic patterns that have Rent’s rule properties?
  - Fast and simple way to evaluate an NoC design
  - More accurate representation of communication locality (CPD) than traditional synthetic workloads
  - Simulate hypothetical workload scenarios by varying the Rent’s exponent

Rent’s rule traffic patterns

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- The probability of communication between two nodes with distance *d* apart is? (Adapted from Davis *et al*., 1998)

$$\begin{aligned} P(d) &= \frac{1}{4d}\left[(1+d(d-1))^p - (d(d-1))^p\right. \\ &\quad \left. + (d(d+1))^p - (1+d(d+1))^p\right], \end{aligned}$$

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```
For each source node $i$:
    For each destination $j$:
        generate a packet from $i$ to $j$ with probability $P(d_{i,j})$
```

Method Validation

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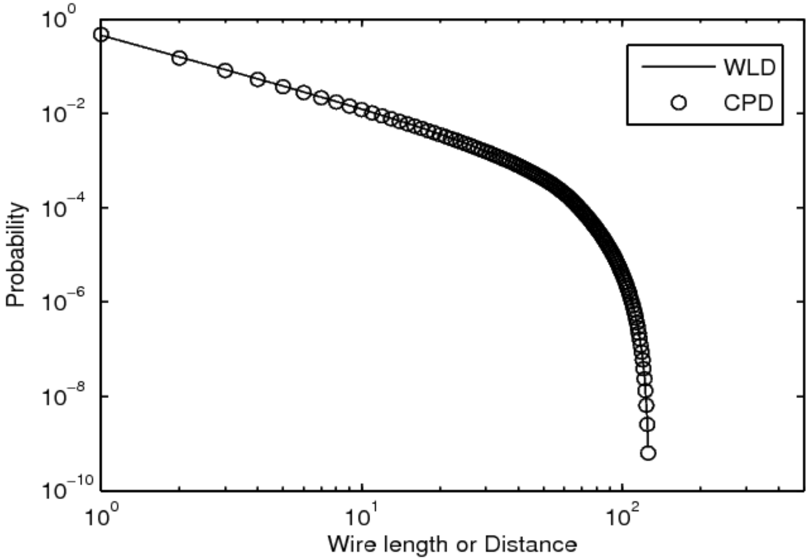
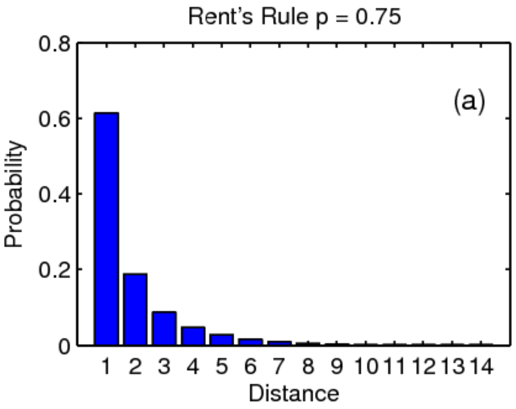


Comparison with other synthetic workloads



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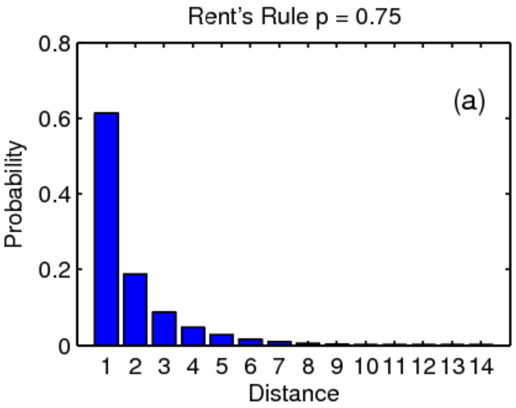

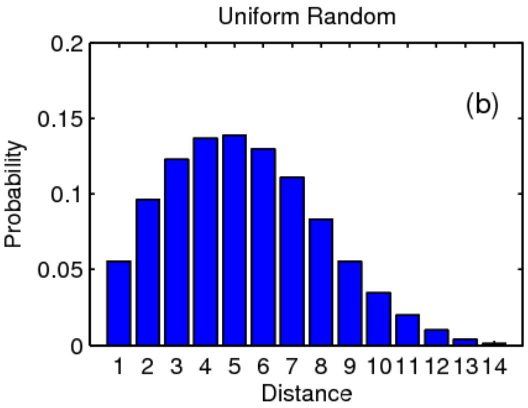

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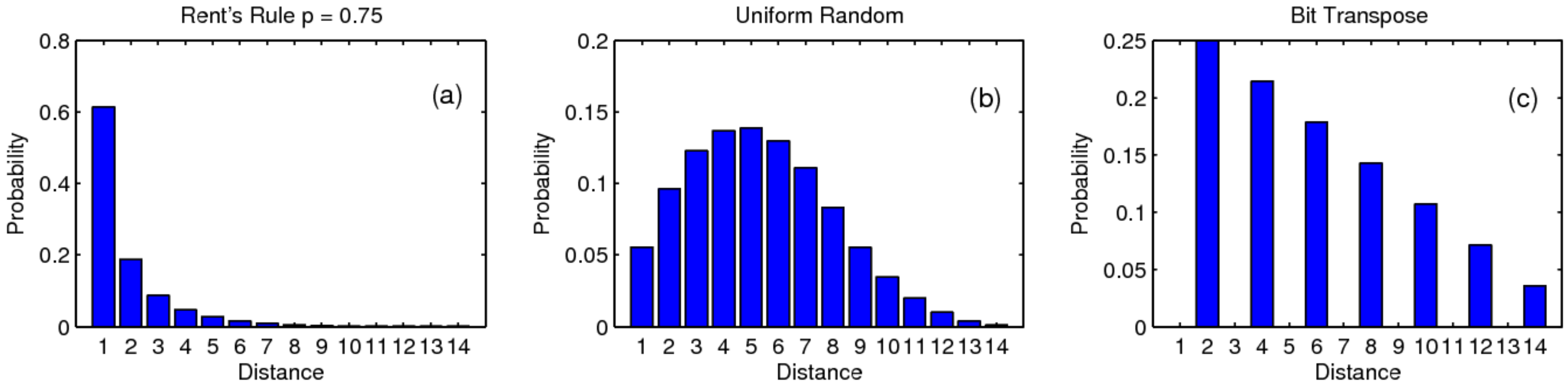

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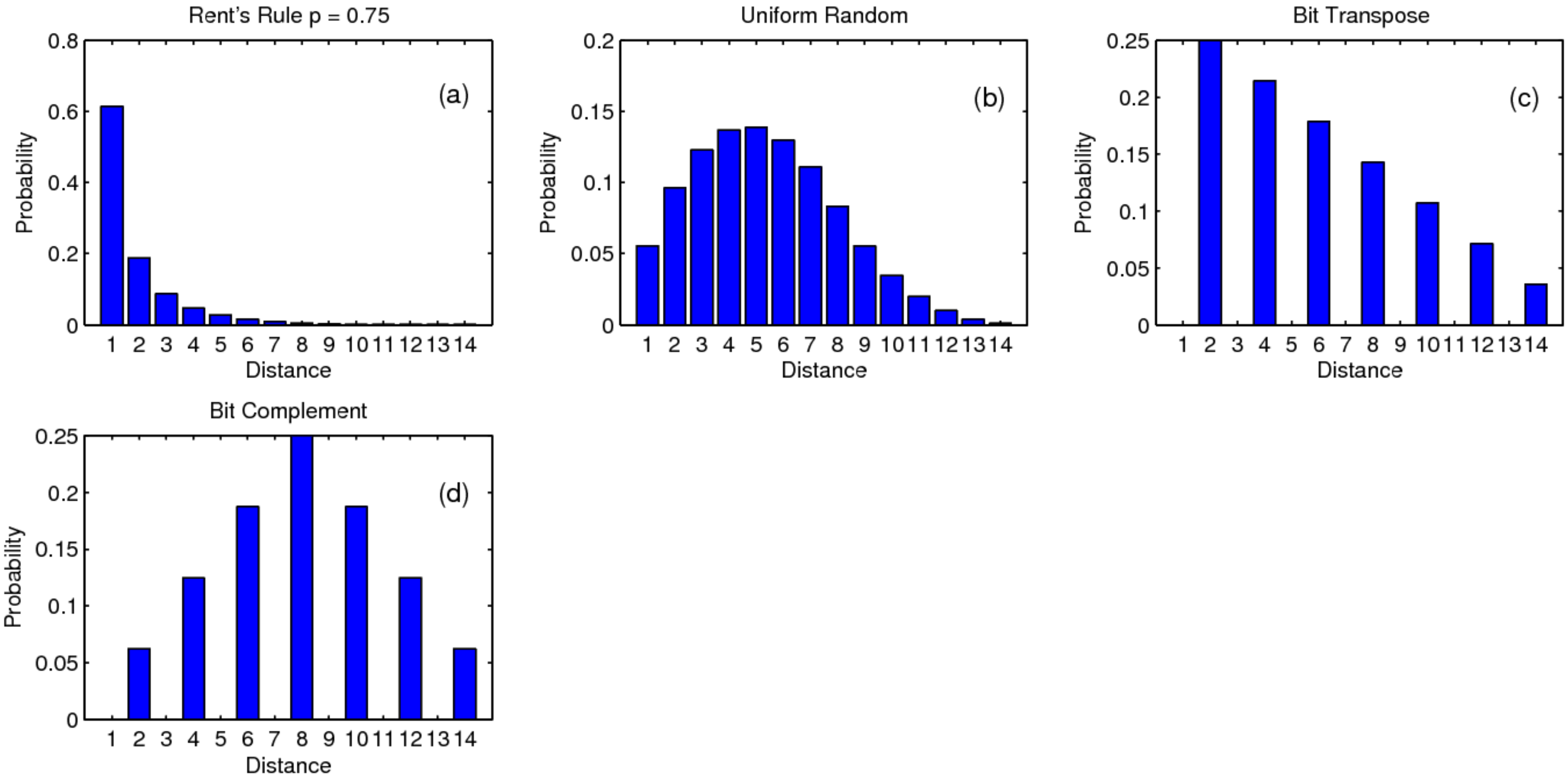

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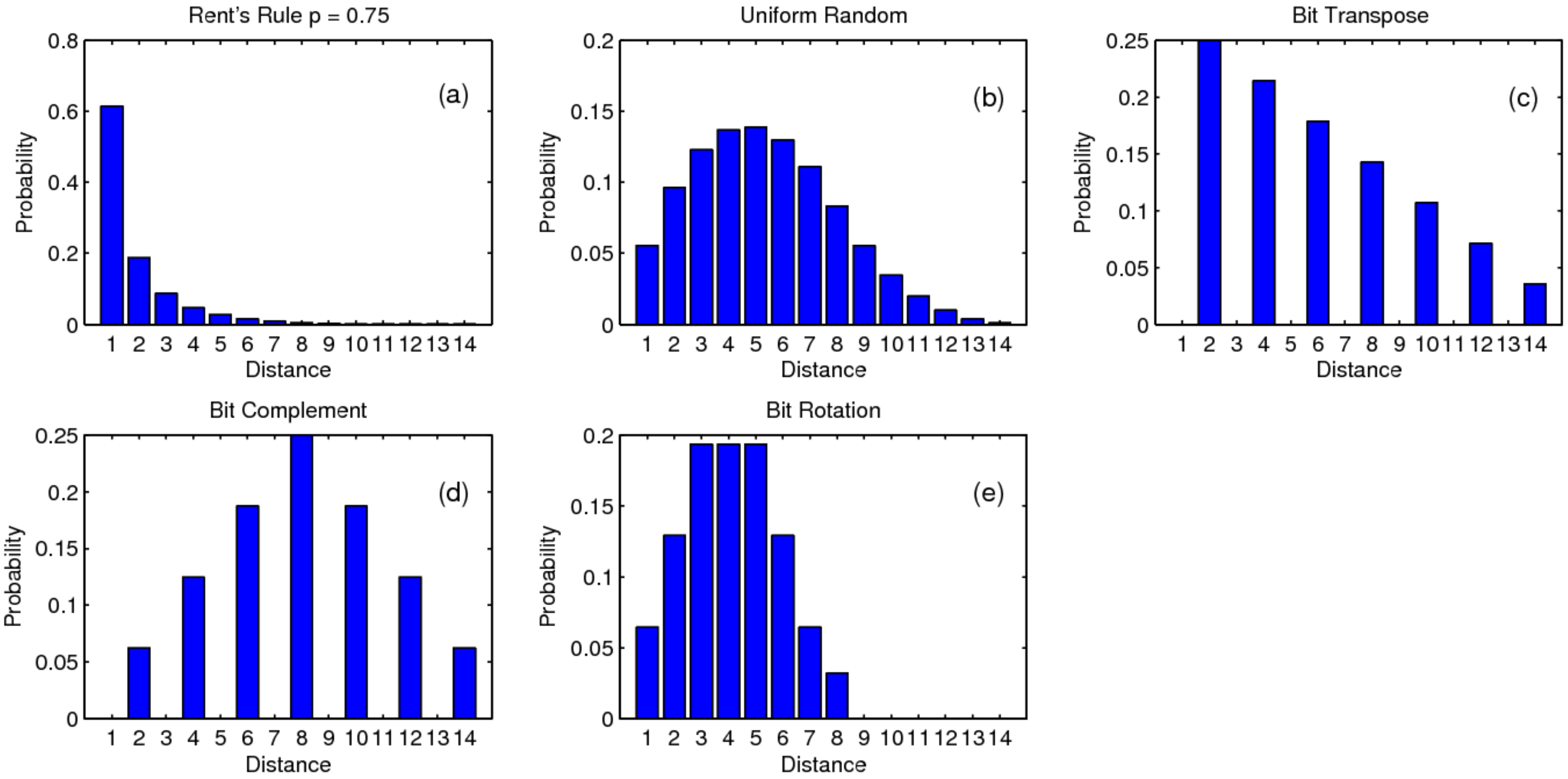

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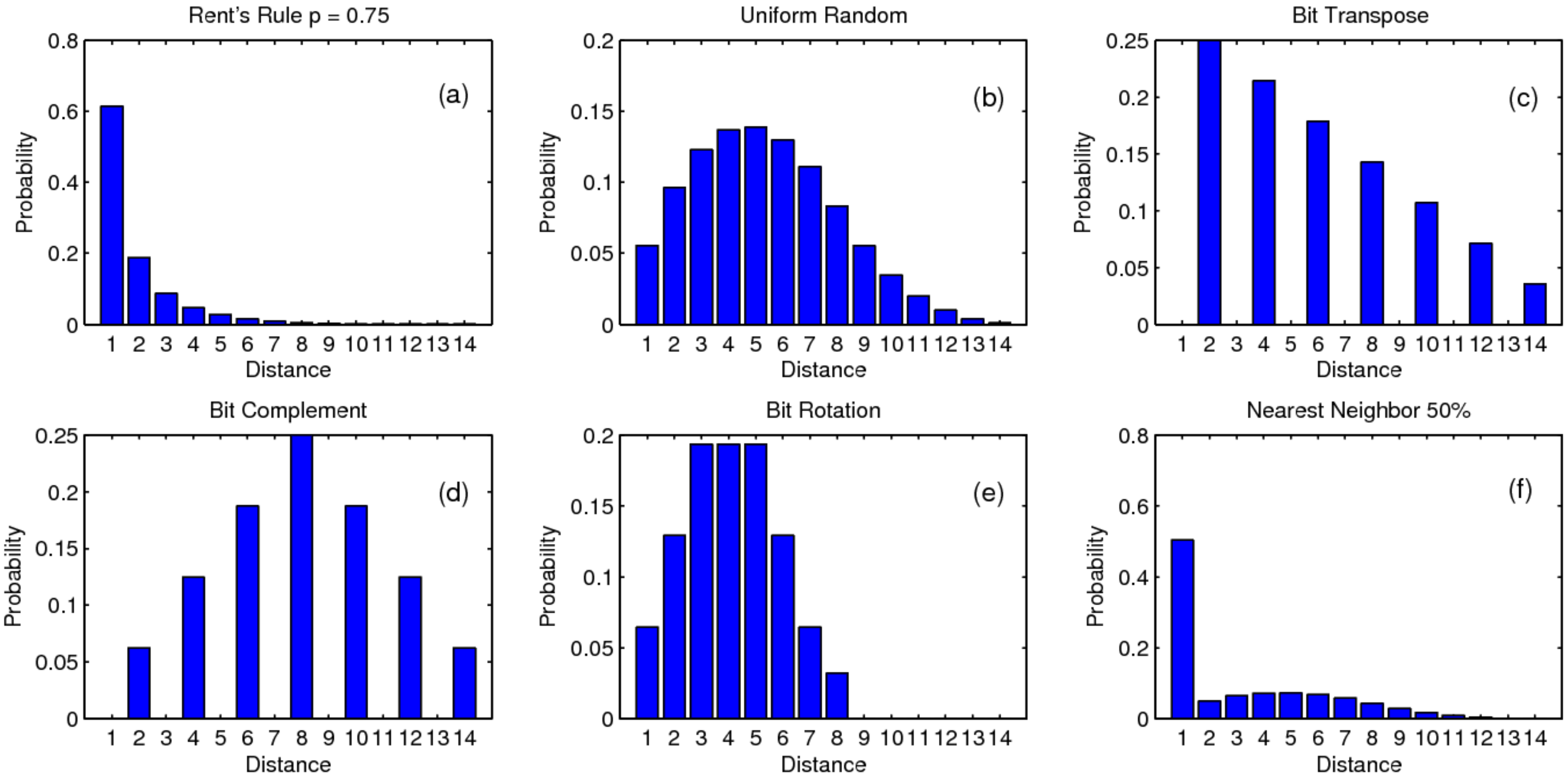

Modeling energy consumption using the CPD

- Can we use the CPD to predict the energy consumption of an application?
    - Energy is roughly proportional to the distance traveled by a packet
    - Fast and simple way of assessing NoC energy consumption
    - Simple way to evaluate application mapping techniques
    - Aid in the design of energy-efficient applications

Energy Model

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3) Total energy:

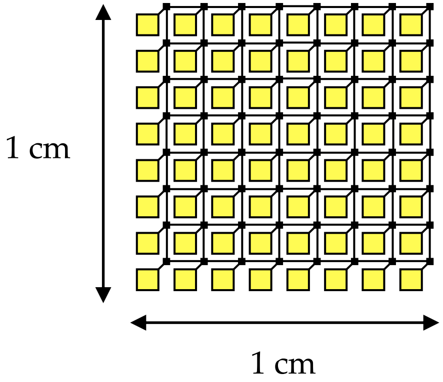
$$E_{total} = N_{packets} \cdot N_{flits} \cdot \sum_{d=1}^{max} E_{flit}(d) \cdot CPD(d)$$

Experiments

- Make energy predictions using our model
- Compare with simulations using Orion
- 8x8 (65nm) and 10x10 (45nm) NoCs
- 7 synthetic traffic patterns

Results

64 cores, 65nm, 1GHz



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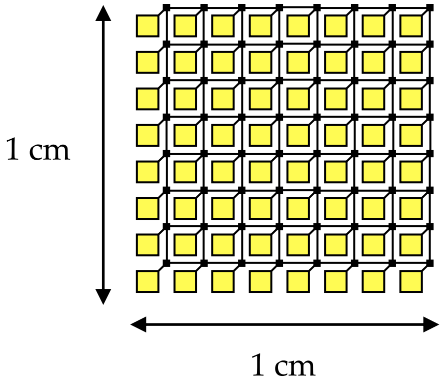
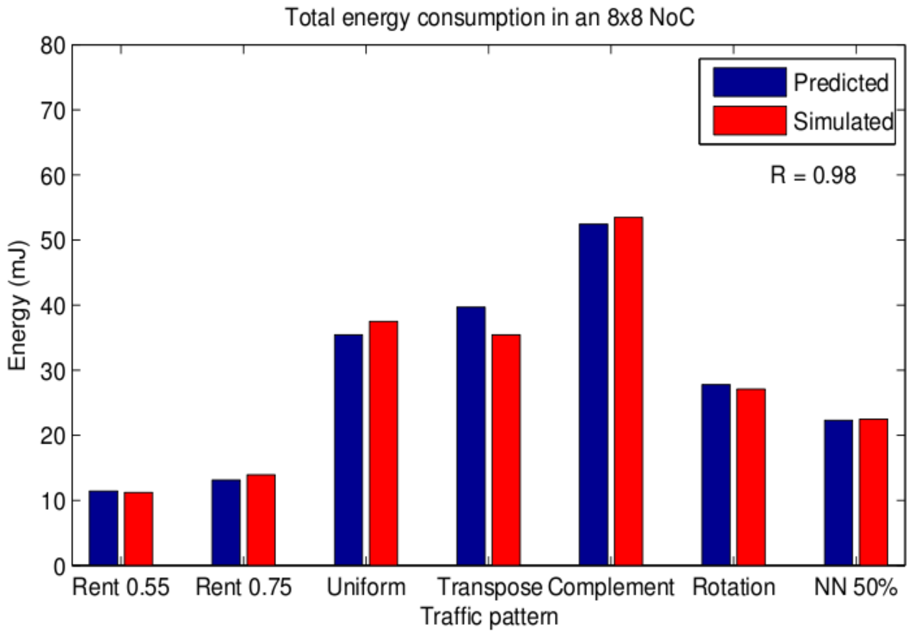
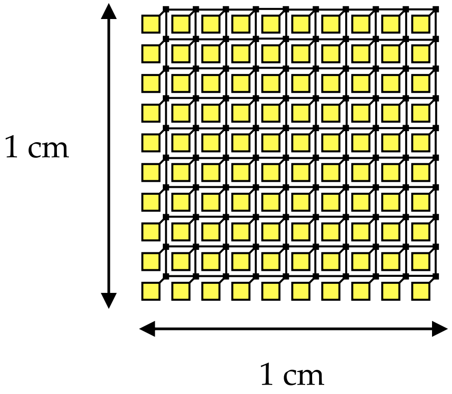




Results

100 cores, 45nm, 3GHz



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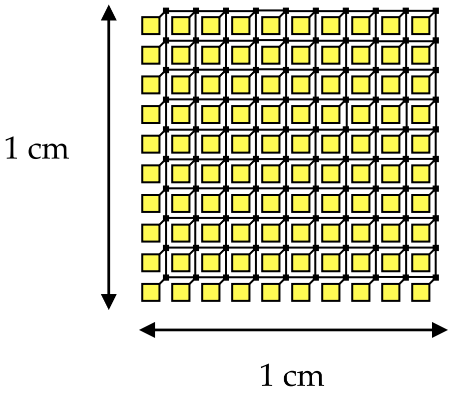
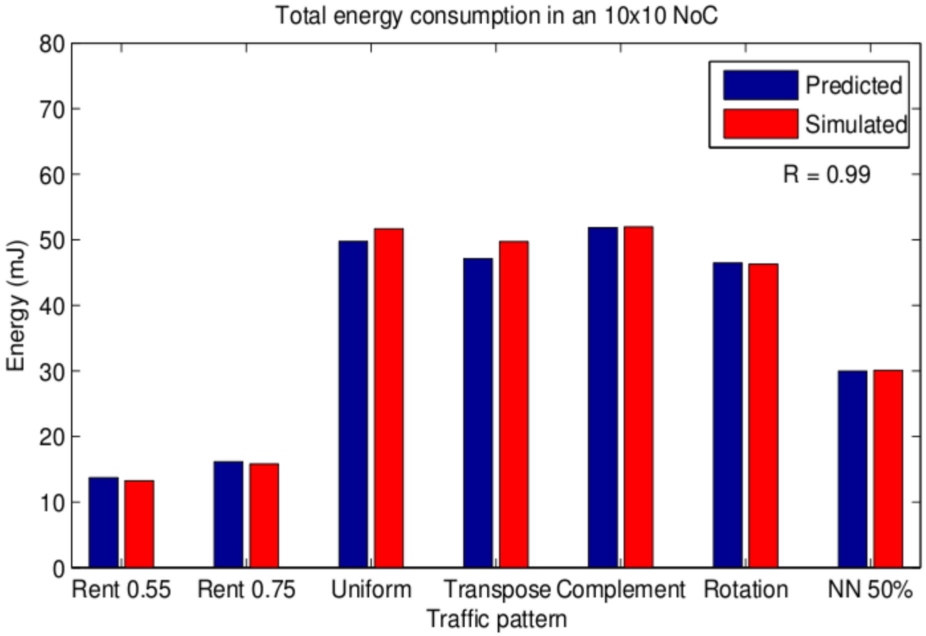




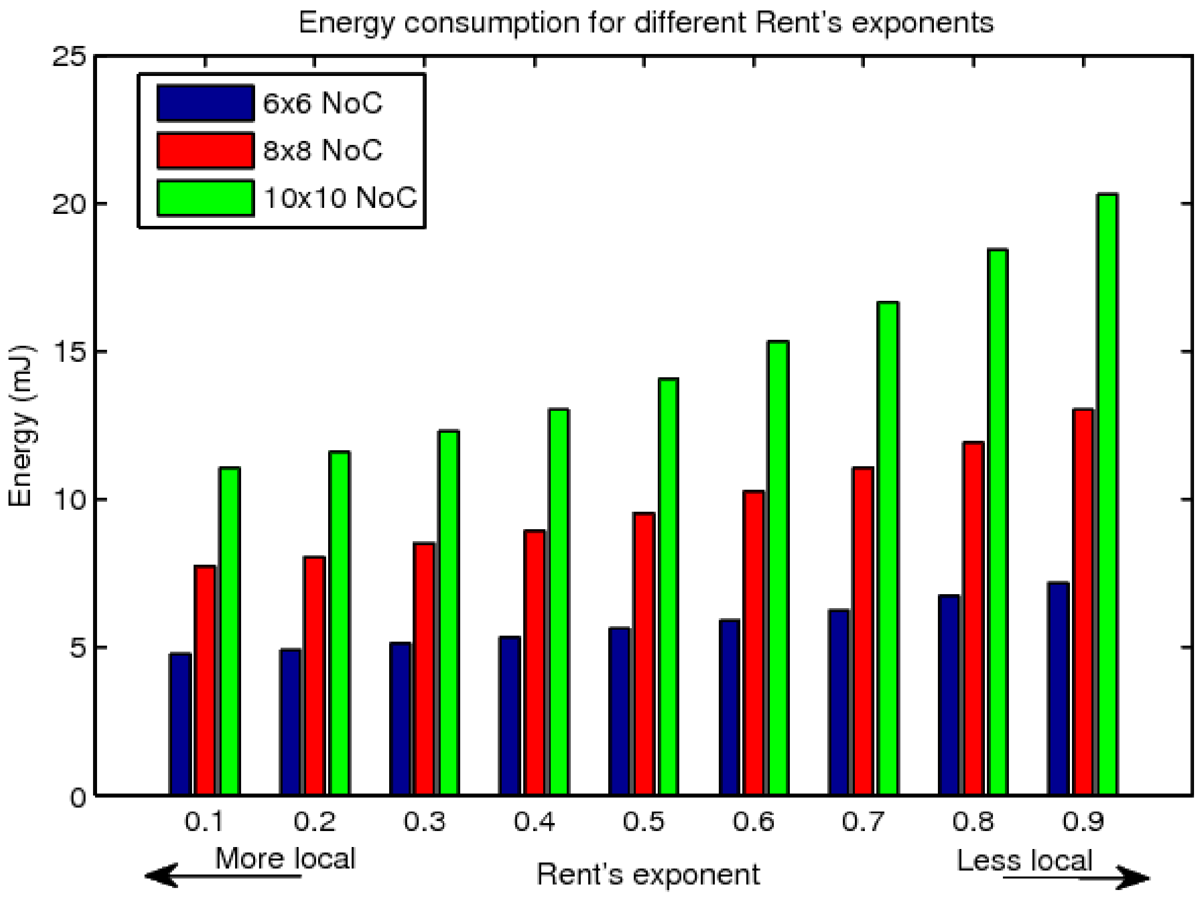
Varying the Rent's exponent

- What is the impact of the Rent's exponent on energy consumption?
  - Our Rentian traffic method can be used to represent a continuum of application complexity scenarios.
  - We will look at NoC energy consumption as a function of the Rent's exponent and size of the system.

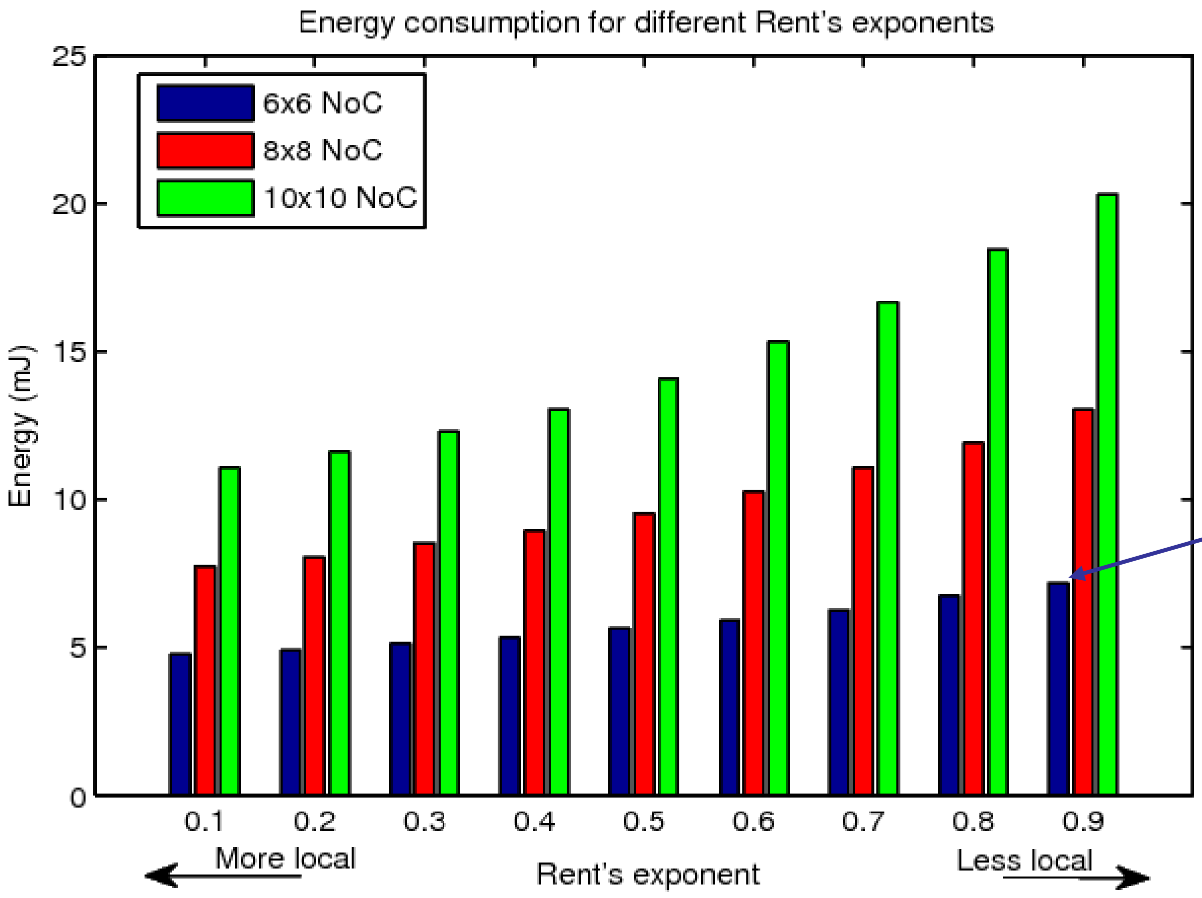
Experiments

- Generate Rentian traffic for $0.1 \leq p \leq 0.9$
- Simulate and measure energy consumption for 6x6, 8x8, and 10x10 NoCs

Results


Energy consumption for different Rent's exponents
Energy (mJ)
25
20
15
10
5
0
6x6 NoC
8x8 NoC
10x10 NoC
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
More local
Rent's exponent
Less local

Results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51%

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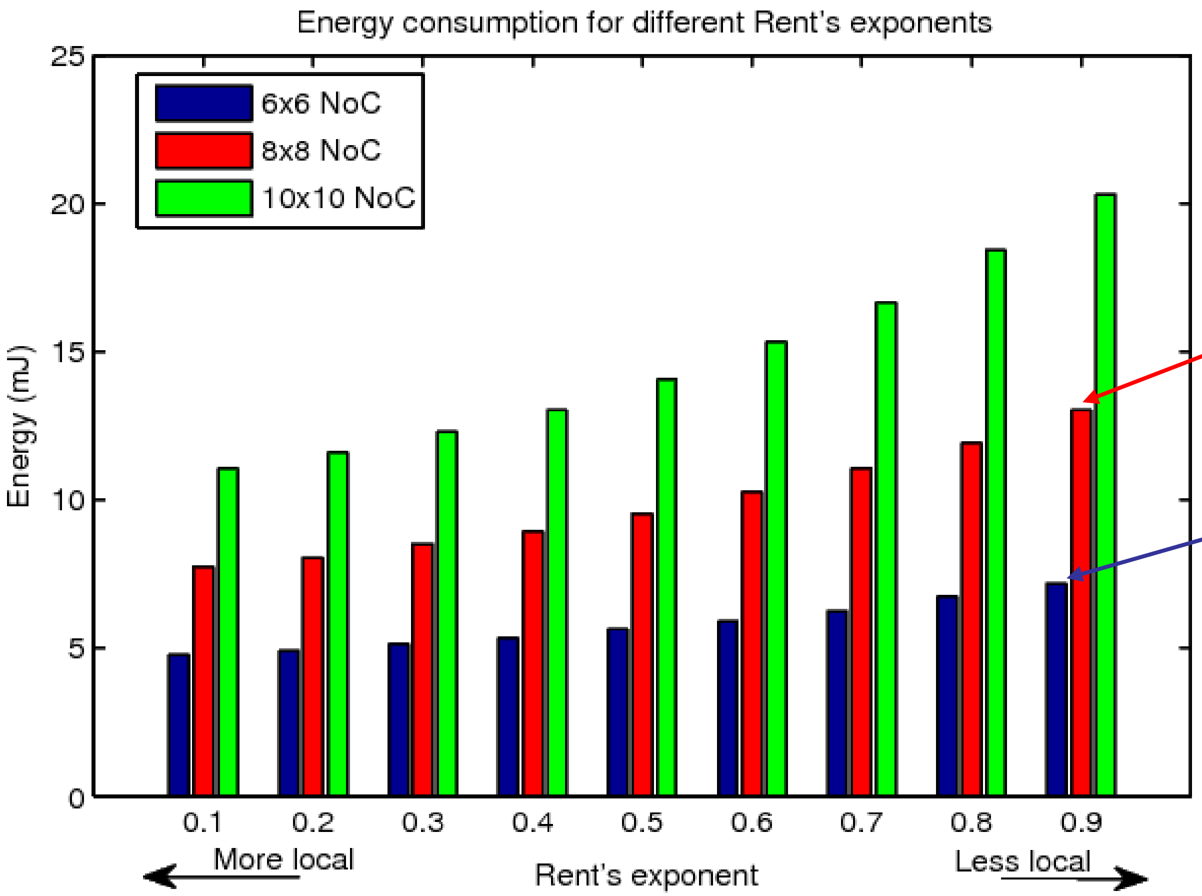

68%

51%

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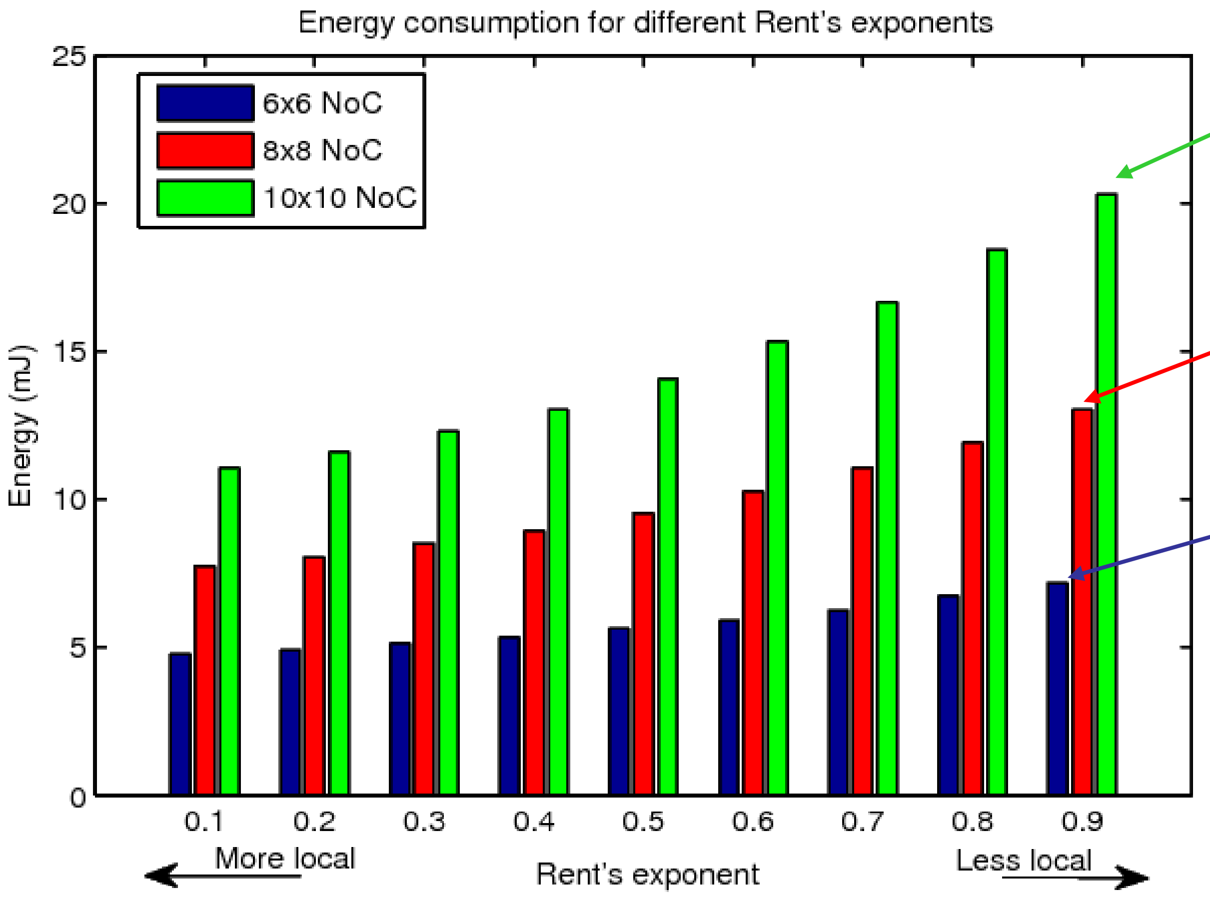

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- We proposed a method based on Rent’s rule that produces synthetic traffic with more realistic CPD.
- We proposed an energy prediction model based on the CPD with excellent results. For traffic that follows Rent’s rule, energy can be estimated directly from the Rent’s exponent!
- Using our Rent’s rule traffic model, we verified that communication locality has a large (non-linear) impact on energy consumption. This impact will be higher for larger systems.

References

- **Davis *et al*. (1998)** Stochastic wire length distribution for Gigascale Integration (GSI) – Part I: Derivation and validation, *IEEE Transactions on Electron Devices*, VOL. 45, NO. 3, MARCH 1998.
- **Greenfield *et al*. (2007)** Implications of Rent’s rule for NoC design and its fault-tolerance, *Proceedings of the First International Symposium on Networks-on-Chip* (NOCS'07).
- **Heirman *et al*. (2008)**, Rent's rule and parallel programs: characterizing network traffic behavior, *Proceedings of the 2008 international workshop on System level interconnect prediction* (SLIP’08).

Acknowledgements

- National Science Foundation, grants CCF 0621900, CCR 0331580, and SHF 0905236
- Air Force Office of Scientific Research MURI grant FA9550-07-1-0532
- US Department of Energy, Office of Science, grant DE-SC0002113
- Santa Fe Institute
- Program of Interdisciplinary Biological and Biomedical Sciences (PiBBS)