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# Analytical Study of Traffic Behaviour in a Network on Chip Architecture

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**Abstract**

*A minimal model of computer network traffic has been defined in simple as well as complex networks in order to study the trade-off between topological-based and traffic based routing strategies. The traffic exhibits a phase transition from a low to high congestion state measured in terms of average travel time of packets as a function of packet creation rate in network. This analysis results in a collective behaviour of traffic which presents second-order as well as first-order phases transition between a free-flow phase and a congested phase. Global performance, enlarging the free-flow region is improved by traffic control in heterogeneous networks. Traffic control also introduces non-linear effects, may trigger the appearance of a congested phase in a discontinuous manner. This paper presents an analytical study of the traffic behaviour in a NoC architecture.*

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## Introduction

The task of designing cost effective networks that provide the required quality of service under varied traffic conditions demands a formal scientific basic. Such a basic is provided by "TRAFFIC ENGINEERING" or "TELETRAFFIC THEORY".

Network Traffic control is used for the better management of power consumed by networked computational resources. As we know, in NoC [2] the energy consumption is often a major concern because the energy for global communication does not scale down whereas computational and storage energy greatly benefits from device scaling(smaller gates and smaller memory cells).On the contrary, global communication on chip will require increasingly higher energy consumption as seen by projections based on current delay optimization techniques for global wires. Hence, communication energy minimization will be a growing concern in future technologies. In integrated circuit [1], interconnect wires account for a significant fraction (up to 50%) of the energy consumed and this fraction is only expected to grow in future. In fact, it was projected that the delay and energy consumption of global interconnect structures will prove to be a major bottleneck for SoC design as technology scales to the nanometer regime. With designers striving to improve the lifetime of battery operated, personal computing devices, minimizing the energy consumed in on-chip interconnects becomes crucial. The requirements for this task are the use of a structured, interconnect oriented, design methodology at all layers of the hierarchy from the system-level down to physical design.

### Observation of information flow density fluctuation

A whole new set of challenges has been posed on designers by interconnect oriented design. Also, the advent of deep sub-micron technology brings several signal integrity issues to the forefront. Multi-billion transistors are going to be expected with the next generation SoCs, ensuring efficient and reliable transport for data signals becomes a daunting task indeed. Existing low power system design methodologies are ill-equipped to tackle this problem and the reason is that the aim is to eliminate all noise related errors through fine-tuned circuit design while it follows an error avoidance paradigm. Clearly, this will become very costly, if not impossible, given the complexity of future SoCs. So the requirement is that, after a moderate amount of design time optimization, the focus is on error resilience techno-quest to combat run time errors and ensure correct system functionality and for this purpose, the paradigm has to change to one of error tolerance.

An interdisciplinary new field of science [3] is growing with the growth of Internet Computer scientists; mathematicians and statistical physicists are now working on this emerging field focusing especially on the fractal properties of the fluctuations of information traffic.

In 1994, [3] Leland et al. reported a statistical self-similarity in the no fluctuation of packets in an Ethernet cable inside a laboratory. In the same year Casbai independently discovered another self-similarity in the fluctuation of round trip times of the "ping"-command which indirectly reflect the level of congestion along a path in the Internet.

### Computer network traffic

The packet delivery from source to destination is completely at random and this randomness is, but naturally, the function of traffic conditions on the channel. Though channel utilization is increased using the concept of virtual channel, the non-availability of virtual channels is also a limiting factor while dealing with the switches. With the increasing packet size, the delay increases (almost linearly). Computer network traffic can exhibit a phase transition from a low to high congestion state measured in terms of average travel time of packets as a function of packet creation rate in network.

Through simulations on a two-dimensional lattice model network, it has been found [3] that the phase transition point into the congestion phase depends on how each router chooses a path for the packets in its queue. In particular, an appropriate randomness in path selection can shift the onset of traffic congestion to accommodate more packets in model network. Numerical simulation of packet traffic on an artificial network not only clarifies that the phase transition is a continuous phase transition accompanied with critical behavior, but it also demonstrates that the critical point which is technologically very important by information can be injected, while above the critical point the possibility of loosing packets due to overflow increases rapidly, namely the total flow rate is the largest and reliability is high at the critical point.

The dynamic properties of a collection of models [6] for communication processes, characterized by a single parameter '€' representing the relation between information load of the nodes and its ability to deliver this information as:

1-The critical transition to congestion reported so far occurs only for '€'=1. This case is well analyzed for different network topologies.

2-For '€' <1, no transition to congestion is observed but it remains a crossover from a low-density state.

3-For '€'>1, the transition to congestion is discontinuous and congestion nuclei arise.

Now the complex networks are defined as the interaction between the elements of social, technological, biological, chemical and physical systems. A lot of interest among the scientific community has been generated with the study of topological properties in such a network. Part of this interest comes from the attempts to understand the behavior of technology based communication networks such as the Internet, the World Wide Web, e-mail networks, or phone call networks. The study of communication process is also of interest in other fields, notably in the design of organizations. It is estimated that more than one-half of the US work force is dedicated to information processing, rather than to make or sell things in the narrow sense.

The network architecture [4] considered in the model consists of nodes placed as a two-dimensional lattice in Fig. 1 a. It is a square with N nodes routers on each side and N2 nodes as a whole. Packets are generated and destroyed on nodes on the boundary of the lattice squares in the figure, but not on inner nodes circles. Inner nodes only forward packets received from neighbour nodes. A node on the boundary generates a packet according to the Poisson arrival with I and sends it to a destination node selected randomly from among the nodes on the boundary including itself. Each node has a receiving queue of unlimited length through which packets are forwarded to the destination and then destroyed.

The probabilistic routing strategy that we compare with this deterministic routing is given by introducing a particular form of routing probability function. When we have multiple routes A and B based on the destination address, we assign the probability to choose a route A or B by the following equation:

$$P(A)=\frac{e^{-\beta X_A}}{e^{-\beta X_A}+e^{-\beta X_B}}. \qquad (1)$$

$$P(B)=\frac{e^{-\beta X_B}}{e^{-\beta X_A}+e^{-\beta X_B}}. \qquad (2)$$

$$1=P(A)+P(B). \qquad (3)$$

where b is a parameter. XA and XB are the number of packets the router has already sent in the direction of A and B.

### Phase transition in traffic network

In future, emphasis can be put on to find a generalized trade off analysis between the area and the performance while increasing the number of virtual channels. The net bandwidth can be better utilized by increasing the number of virtual channels; on the other hand it will increase the cost while considering the chip area a cost factor. A comparative analysis of variable packet size and fixed packet size along with the generalized latency and throughput can be a point of emphasis in future.

The phenomenology [4] of the nature of computer network traffic has commanded much attention recently. Analysis, simulation and experiments based on such concepts as "phase transitions" and "self-similarity" are active research topics in physics as well as in computer science. The approach is first to create a simple simulation model for network traffic. Then a probabilistic routing strategy is proposed that can shift the phase transition point. To gain more insight into this effect, the number of routers is varied that take this probabilistic strategy. It was found that the effectiveness of model shows a nonlinear response as a function of proportion of probabilistic routers.

In order to observe fluctuations of information flow in the internet [3] a personal computer is set as a host on an Ethernet cable that connects the gateway of Keo-university and WIDE internet backbone that belongs to the public domain. The data link layer of campus backbone 20Mbps ATM and a gateway is connected to the network operating centre of the WIDE backbone by Ethernet of 10 Mbps. Our monitoring host is connected to this segment via a non-intelligent hub.

The recent enormous development of the computer network, the internet has been attracting much attention not only by computer scientists but also physicists as a new target of statistical physics. The internet system has been widely spread in our daily life, exchanging information by e-mail, performing the operations using information services like www etc. The information is sent from each local computer in the form of packets in which the sender's address and the destination are recorded. A bigger unit of information is divided into a set of many packets.

Here the focus is [5] on an essential feature of the topological structure of the internet. Thousands of small local networks are linked to each other by cables and technical joints such as gateways to construct the Internet which makes topological hierarchical structure. Roughly speaking, a schematic view of the connection is like a branching tree; terminals are on the very tip of network tree, and bunches of computers are connected to a bunch of upper level groups are connected to still higher grade group, and so on. It can be approximated that the structure of the Internet with the Clayey-tree(or Bethe lattice) by ignoring loop structures, gateways and cables corresponding to sites and bonds, respectively because the gateways are playing the role of bottlenecks in jamming processes.

### A map analysis of information fluctuation

In this section we analysis the sort time co relation of information flow fluctuation by introducing a map analysis that is a plot of An v/s Xn+1, where An denotes the flow density at time step n.

After summarizing the observation facts on the relation and v/s Xn+1, we can assume the following first- order autoregressive map with an external random force term, finals the simplest approximation,

$$X_{n+1} = g(A_n) + F_N$$

Here, the map function g(X) is empirically constructed from the measured data by introducing a piece wise linear function with two bending points for g(X);

$$g(X) = \begin{cases} a_1 X + b_1 & \text{for } 0 < X < c_1, \\ X + b & \text{for } c_1 \leqslant X < c_2, \\ a_2(X - 1.0) + b_2 & \text{for } c_2 \leqslant X \leqslant 1.0, \end{cases}$$

Where the maximum flow is normalized to 1.0.The parameters, C1 & C2 indicate the bending point, b1 & b2 are the minimum and maximum values of the mean values. The parameter b is the most important parameter that controls the mean flow density .For b<0 the generated traffic has a low mean flow density fix point corresponding to the sparse phase and for b>0 the generated traffic belongs to the congested phase .The critical point by the condition b=0 which means that all the traffic points over the range of C1<X<C2 are the fixed points ,thus the variance of the fluctuation becomes very large .The values of a1 a2 indicates the line slopes in the small and large flow density range and are determined by requiring the continuity of g(X) .As a best fit with the observation set the parameters C1=0.25, C2=0.75, b1=0.1 & b2=0.9

The generated fluctuations capture all the basic phase transition properties of the real fluctuations qualitatively as for the probability density shapes, the peak point shifts, the width broadening, the rapid increase of auto correlation time and the power–law distribution of the interval of the successive high- density flows. However, from the quantitative view point the critical exponents do not fit perfectly. There can be a rich variety of phase transition behaviors and it has been seen that the Internet can be viewed as a huge composite of phase transition elements. Due to buffer's non liner property, each router can show a phase transition behavior microscopically. Due to contagious propagation of congestion among routers there occurs another type of phase transition macroscopically. By observing information flow density at a point we can find phase transition behavior from the fluctuations in the time sequential data. In order to confirm the validity of this data analysis method we perform several other observations at different observation points .In any case [3] all the results are consistent .An interesting finding is that the estimated critical flow densities are about 60% of the maximum flow density in general. It is technologically very important to estimate the critical density because packet loss probability becomes dominant at flow density higher than the critical point.

The study of properties of Ethernet connection by numerical simulation as the physical mechanism of present phase transition is not elucidated yet.

There is an interesting rule [3] of avoiding collisions of information packets in the Ethernet communication called the back-off.

The back-off rules are very complicated, but in a rough sense the rules are given as follows; when two routers shearing an Ethernet cable are trying to send information packets, the one that has just sent a packet successfully has a priority to emit the next packet and the other router must wait. By this effect there occurs a new type of phase transition between two phases; one phase is a low-density mixed flow phase and the other is a high-density oscillatory phase in which active router switches nearly periodically.

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