

Dynamical traffic analysis on scale-free networks

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ABSTRACT

Evaluation of trade-offs between dynamical characteristics and architecture design on large-scale networks is demanded for engineering solutions. We study dynamical characteristics of complex networks through both packet traffic simulation and theoretical network analysis to explore high-performance NoC (network-on-chip) architectures. To achieve efficient communication with hundreds of functional modules implemented on a chip in the future, scale-free network is considered as one of the promising topologies for constructing on-chip networks. In scale-free networks, we focus on pair degree-degree correlations that indicate average degree of the nearest neighbors of a node, and investigate their topological effects on NoC performance. The network architecture constructed with the topology such as hubs mostly connect to lower-degree nodes can disperse traffic load efficiently and avoid the extreme concentration of load on hubs.

Categories and Subject Descriptors

C.1.2 [Multiple Data Stream Architectures (Multiprocessors)]: Interconnection architectures; C.2.1 [Network Architecture and Design]: Network topology

Keywords

Topology, Traffic analysis

1. INTRODUCTION

A number of complex networks in real world are called scale-free networks whose degree distribution $P(k)$ is approximated by a power-law $P(k) \propto k^{-\gamma}$, where k is degree and the exponent γ depends on each network structure. In scale-free networks, a few nodes called hubs have higher degree than other nodes and play a dominant role to conserve connections of the overall network. Although static characteristics of complex networks have been well recognized, it is much more complicated to acquire their dynamical characteristics. In our study, we evaluate trade-offs between

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topology and dynamical characteristics through packet traffic analysis on scale-free networks.

Evaluation of trade-offs between dynamical characteristics and architecture design on large-scale networks is demanded for engineering solutions. Nowadays to achieve large-scale and high-performance communication on VLSI chips, the design paradigm of NoC (network-on-chip) [1], whose technologies are applied from the field of conventional packet-based computer network communication, is proposed.

Traffic performance depends on network topological characteristics. There exist some scale-free networks whose topologies are quite different although they have the same degree distribution [2]. These topological differences come from pair degree-degree correlations, which refer to the topological tendency between the degrees of a certain node and the degrees of the nearest neighbors. The differences of pair degree-degree correlations change the local topology adjacent to hubs, which affects the characteristics of the whole network. In this study, we explore the efficient scale-free network topology for large-scale NoC design by packet traffic simulations on the networks whose pair degree-degree correlations are different.

2. METHODS

2.1 Network topology

We construct three router-level architecture models where pair degree-degree correlations are different as shown in Figure 1, although their degree distributions are identical. One of the models is H-L (High degree - Low degree) model which has the pair correlations that higher-degree nodes connect to lower-degree ones. In H-L model, as the degree of a node increases, the average degree of a neighbor decreases. The second is the P-A (Preferential Attachment) model, where the network is constructed by adding nodes according to preferential attachment rule. In P-A model, the average degree of a neighbor does not increase so much even if the degree of a node increases. The other is H-H (High degree - High degree) model where hubs, contrary to H-L model, connect to other hubs directly as often as possible. In H-H model, as the degree of a node increases, the average degree of a neighbor also increases steeply.

2.2 Simulator and Traffic model

To evaluate performance of NoC architectures, we adopted the network simulator ns-2 [3] which is used for dynamical

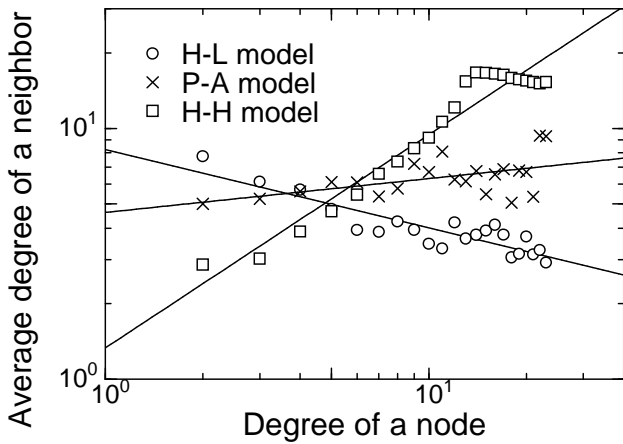


Figure 1: Pair correlations of the degree of a node versus the average degree of a neighbor in H-L, P-A, and H-H models. Each solid line is fitted by a power-law. These correlations are the case where the number of nodes is 900 in each model.

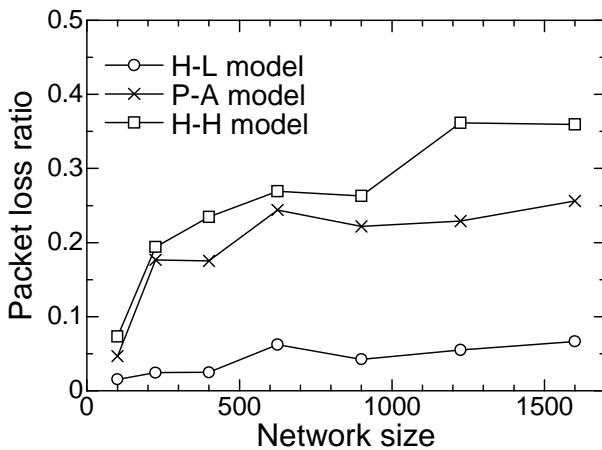


Figure 2: Variation of packet loss ratio with network size.

traffic analyses of packet communication. We assumed the buffer size of output queues in both ends of a link is 4 packets. In a simulation, all module nodes are traffic sources that transmit packets, and the destination of each traffic is selected randomly in all of the module nodes. In this study, performance metrics of NoCs is packet loss ratio which is defined as probability of packets dropping from queues before reaching its destinations due to congestion in overall packets generated by every traffic source.

3. RESULTS AND DISCUSSION

Figure 2 shows the variation of packet loss ratio with network size (the number of nodes included in the network) for all the models. The packet loss ratio does not almost increase in H-L model and the value of the ratio is the smallest even if the network size becomes larger. On the contrary, as the network size becomes larger, the packet loss ratio increases in P-A and H-H model.

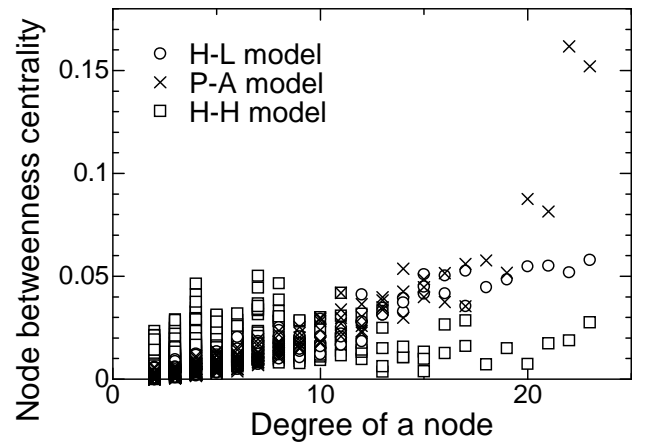


Figure 3: Plots of the betweenness centrality versus degree of every node for H-L, P-A, and H-H models. In all cases the number of nodes is 900.

Packet loss often occurs at traffic bottlenecks of networks, so we examine where the traffic load is concentrated. Betweenness centrality [4] is the index that counts the fraction of shortest paths between all possible pairs of nodes passing through a given node or edge. We compare the distributions of the relation between degree and node betweenness centrality of all nodes for H-L, P-A, and H-H models, as shown in Figure 3. In H-L model where hubs are dispersed moderately, the betweenness centrality increases gently as the degree of a node increases and there are no nodes whose betweenness centrality is extremely high. Consequently, hubs are not loaded on too much and traffic load is dispersed efficiently, so there are few traffic bottlenecks in H-L model architecture. In P-A model, the betweenness centrality of hubs is much higher than that of lower-degree nodes. This topology results in extreme concentration of traffic load on hubs and a lot of packet loss near hubs. In H-H model, there are a lot of lower-degree nodes whose betweenness centrality is higher than that of hubs, so this parts result in the traffic bottlenecks of congestion. Extremely localized and dense interconnections of hubs cause a lot of bottlenecks in remote places from hubs. In this way, the results presented in this study show the scale-free network topology where hubs connect to lower-degree nodes is the most efficient to construct NoC architectures.

4. ACKNOWLEDGMENTS

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