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PowerAntz: Ant behavior inspired power budget distribution scheme for Network-on-Chip systems

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ABSTRACT

In Network-on-Chip (NoC) based complex system design on-chip power management is a challenging issue. Most power management schemes fail to provide optimal power sharing among on-chip routers when the power budget distribution varies significantly due to their non-uniform placement on chip. This paper presents PowerAntz, an ant system inspired distributed power management strategy for NoC based systems. This is an adaptive and distributed approach to power sharing across routers of a large network on chip and it is shown to be a scalable solution. A detailed flit accurate simulator was developed in SystemC to evaluate the efficiency of the technique. The experiments demonstrate PowerAntz to be up to 30% more effective in distributing power budget compared to existing strategies. Further, it also achieves up to 21.25% improvement in power budget utilization while keeping the energy overhead negligible for best case scenarios.

1. Introduction

Network-on-Chip (NoC) has emerged as a promising interconnect platform for large scale System-on-Chip (SoC) design. NoC provides the required infrastructure for reliable communication that is based on globally asynchronous and locally synchronous paradigm [4]. Being an active component on the chip the network accounts for a significant share of chip power consumption [11]. Low power dissipation ability limits the power consumption that may be allowed in a large scale network on chip. Hence efficient power management technique is necessary to achieve maximum performance while maintaining power consumption within limits.

Simple power management offers uniform budget distribution among routers in NoC which may not be adequate for all circumstances. Large scale NoC based systems have non-uniform power consumption due to varying task processing rates and communication requirements [18]. Fig. 1 shows a typical power consumption scenario in a NoC. There can be *hot zones*, i.e. routers need more than allocated maximum power budget to process incoming packets (shown with - in Fig. 1) and *cold zones*, i.e. zones having surplus power budget (shown with + in Fig. 1) within the chip separated by a *neutral zone* (shown with *N* in Fig. 1), consisting of routers consuming power as allocated. Existing power management schemes like PowerHerd [2], PC [3] do not provide enough flexibility to distribute spare power budget from cold zone to hot zones crossing the neutral zone. These schemes restrict power sharing among immediate neighbors. For example, in the scenario illustrated in Fig. 1, with traditional power management even though there is surplus power budget in the cold zone, the hot zone cannot receive the surplus power budget information from the cold zone. Such inefficiencies in power budget allocation lead to underutilization of available power budget and impacts system performance. Throttling of high activity routers also leads to increased idle period in less active routers and consequently increased idle energy consumption as well.

In this paper we present PowerAntz; an ant behavior inspired distributed power sharing scheme in Networks on Chip. PowerAntz attempts to provide improved power budget utilization by allowing power budgets sharing among routers those are beyond neighbors while keeping the distribution overhead to its minimum. This technique utilizes the power sharing history captured in pheromone values to distribute surplus power in the future. The main contribution of this work is a power distribution scheme which is,

- *Efficient*: up to 21% improvement in utilization of power sharing in non-uniform power consumption scenarios when compared to an existing scheme.
- *Lightweight*: Power budget distribution overhead varies from zero to 5% in the best case to the worst case scenario.
- *Scalable*: Scheme overhead remains almost constant with varying network size.

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The rest of the paper is organized as follows. Section 2 describes related works in the area and why there is a scope for PowerAntz. Following that is Section 3 describing the ant system in general. Section 4 describes the formulation of power distribution problem using ant system and the distributed power sharing algorithm given in detail. Section 5 illustrates the simulation environment and the experimental setup followed by various results in Section 6. Section 7 concludes the paper with discussions and future directions.

2. Related works

Both hardware and software approaches addressing NoC power management can be found in literature. Related to this work, we mention only hardware based power management techniques that have been proposed in the literature. There are two approaches to hardware power management in NoC. Low power design in general [5,7] and peak power management [14]. The scope of this work is restricted to peak power management, more specifically addressing the issue of power budget distribution. Power management techniques have been well studied in network on chip domain [6,8,15–17,19]. However, these works differs from PowerAntz because, PowerAntz is about methodology to efficiently distribute the power budget while these works address power management in general. It is possible to integrate PowerAntz with these techniques to provide efficient distribution of power budget. Due to comparability reason, only power management techniques that have some form of budget sharing technique built into it are discussed here.

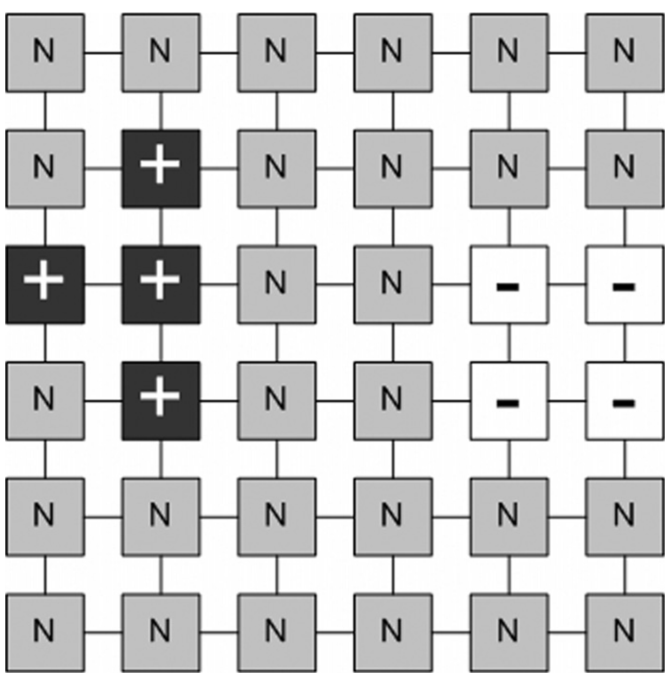

Fig. 1. Large NoC with hot and cold zones.

Shang et al. proposed PowerHerd [2], which handles the power management of a network on chip by sharing power budget among immediate neighbors. PowerHerd shares power budget using explicit control mechanism present among neighboring routers. The design of power herd does not allow power budget sharing between non-neighbor nodes.

Kim et al. proposed PC [3], which does local power management but no sharing of power budget. They have shown improvement in performance in terms of latency compared to PowerHerd. Bhojwani et al. proposed SAPP [14], a non-deterministic peak power management technique that uses immediate neighborhood power consumption information to allocate power budget and periodically adjusts power budget to prevent over allocation. PowerAntz differs from SAPP in the way it shares power budget information. PowerAntz utilizes budget information beyond the immediate neighborhood.

Daneshtalab et al. [12] used AntNet approach for power aware routing but they neither addressed power distribution involved among the components on chip nor dealt with explicit power management.

We have restricted the performance comparisons of PowerAntz with PowerHerd and PC due to architecture similarity and hence the results may be considered as more relevant. Since PC does not do dynamic power sharing and budget distribution we will do a network performance comparison with PC. However, we will compare the power sharing performance and budget utilization with that of PowerHerd.

3. The ant system

Ant system was proposed by Dorigo et al. [1] and has been used by others as a solution strategy for hard problems. Numerous problems have been identified to be solvable efficiently and easily using this idea. Ant system is inspired by the natural phenomenon of ants finding efficient routes to food sources from their habitats using passive information sharing through modification of the environment. This is called Stigmergy.

Fig. 2 illustrates a simple ant system with a food source and an ant home. There are two possible paths from Home to Food and back. Initially each ant chooses any of the two paths randomly with equal probability. When an ant takes a path it leaves a trail of pheromone on that path. The strength/concentration of the pheromone trail left on all path decreases gradually. Now as shown in the illustration some paths are shorter in length than

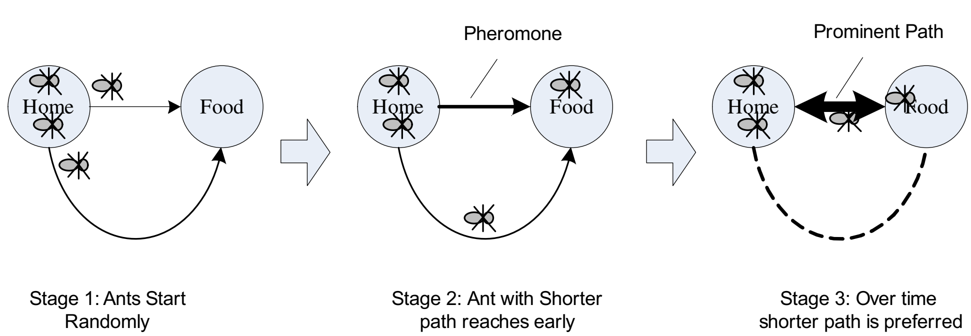

Fig. 2. The ant system.