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On the Impact of Routing and Network Size for Wireless Network-on-Chip Performance

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Article Info

ABSTRACT

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Wireless Network-on-Chip or WiNoC is an alternative to traditional planar on-chip networks. On-chip wireless links are utilized to reduce latency between distant nodes due to its capability to communicate with far-away node within a single hop. This paper analyzes the impact of various routing schemes and the effect of WiNoC sizes on network traffic distributions compared to conventional mesh NoC. Radio hubs (4×4) are evenly placed on WiNoC to analyze global average delay, throughput, energy consumption and wireless utilization. For validation, three various network sizes (8×8, 16×16 and 32×32) of mesh NoC and WiNoC architectures are simulated on cycle-accurate Noxim simulator under numerous traffic load distributions. Simulation results show that WiNoC architecture with the 16×16 network size has better average speedup (~1.2×) and improved network throughputs by 6.36% in non-uniform transpose traffic distribution. However, as the trade-off, WiNoC requires 63% higher energy consumption compared to the classical wired NoC mesh.

1. INTRODUCTION

Technology scaling has allowed the integration of multi-core design that range from hundreds to thousands of processing cores on a single integrated circuit (IC). Nevertheless, the trend of growing numbers of processing cores in Network-on-Chip (NoC) has caused higher latency and more power-hungry system architecture affected by the long distance multiple-hops communication. To date, Wireless Network-on-Chip (WiNoC) is among the promising emerging technology to alleviate the aforementioned issues due to its some unique factors such as energy efficiency, high bandwidth delivery and low latency [5, 2, 8]. Furthermore, these interconnects are also able to transmit data to the other side of chip in single-hop with minimal energy consumption [6].

On-chip wireless interconnects was proposed as the viable alternative for wired communication in order to furnish an effective yet scalable WiNoC architecture. There are numerous architectures of WiNoC that have been proposed, which can be categorized as pure wireless, 2D mesh-based, multiple-tier, small-world and irregular topology. Zhao et al. [13] proposed a multi-channel WiNoC called McWiNoC that uses conventional NoC architecture as a basis, which is very adaptable to the transmission range of its radio hubs. Meanwhile, a network-based processor array (NePA) that is a hybrid WiNoC that extends 2D mesh NoC with a single bidirectional link between two neighbouring nodes was proposed [11]. Authors in [9] have proposed an architecture known as WCube, a recursive wireless interconnects with a multi-tier structure that includes both of the wireless backbone and wired edges. This architecture can cope with scaling limitation of the demand number of on-chip cores. Instead of long wire insertion to improve NoC performance [10], works in [4, 7] proposed a WiNoC architecture based on the small-world features. Wireless links are used to create one-hop shortcuts. These alternatives have proven to enhance the network performance in NoC. In [12], an irregular mesh-WiNoC topology that is established by wireless links has been proposed to provide high efficient and low cost distributed minimal table based routing strategy.

Although there are several new WiNoC architectures have been proposed, those works did not comparatively analyzed on the impacts of different routing schemes and traffic patterns in varied network sizes between generic mesh-WiNoC and conventional mesh-NoC. In this paper, we have made comparative analysis and identify which architecture works best on certain routing schemes, traffic patterns and system sizes. In this work, we analyze the effect of increasing the WiNoC system size under different synthetic

traffic distribution on global average delay, network throughput and power consumption in comparison with conventional NoC for different network scales.

This paper is structured as follows. Section 2 reviews the generic architecture of Wireless NoC. The experimental setup is highlighted in Section 3. Section 4 spotlights the simulation results and discussion. Finally, the conclusion is given in Section 5 with recommendations for future work.

2. WIRELESS NOC ARCHITECTURE

The architecture formation in NoC is among the dominant factors that affect the overall performance and its network cost. NoC topology is constructed by the physical layout, links between IP cores and channels over the network. Therefore, the selection of topology will affect the hops count for a packet to traverse and also the link lengths between source and destination IP cores. Hence, this explains how topology impacts the network latency. Meanwhile, as data traversing process dissipates energy these hop counts indirectly affects network energy consumption.

Most conventional NoC architectures are based on multiple-hops wired interconnections among nodes. Unlike conventional NoC, WiNoC harnesses the wireless connectivity as a means of communication among nodes with reduced network latency, particularly for the far-away nodes. Figure 1 illustrates the generic example of 8×8 (64 nodes) mesh WiNoC architecture with 4×4 radio hubs that are distributed evenly over the network. As depicted, WiNoC can be visualized as a two-level network. The first level is a classical wired 8×8 mesh NoC topology, whereas the upper level is the wireless NoC constructed by a number of radio-hubs. In this example, each radio-hub has a concentration of 4 that is shared by 4 routers of the first level wired NoC network. NoC tiles are augmented with radio hub transceivers that allow single-hop communication between far-away tiles that otherwise would require multiple-hops in the classical wired network.

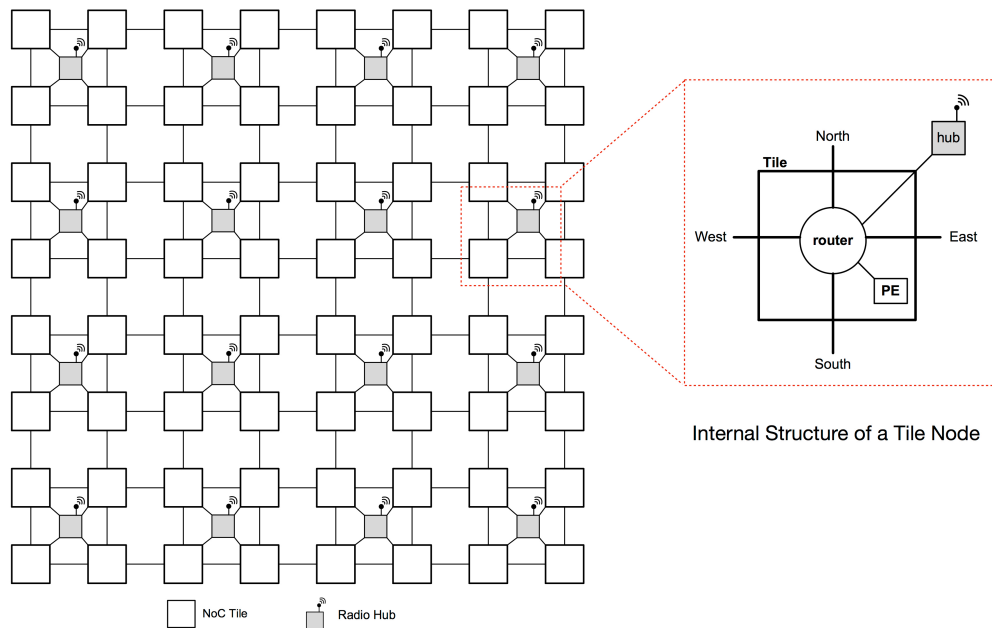


Figure 1. 8×8 WiNoC architecture with 4×4 radio hubs

In WiNoC, the role of radio hubs is in charge of single-hop packet transfer between remote nodes via wireless communication channel. The on-chip antenna and the transceiver are two essential modules in radio hub. The features of both elements are discussed accordingly in Section 2.1 and 2.2.

2.1 On-Chip Antennas

To be practical for the WiNoC architecture the on-chip antenna must be wideband, sufficiently small and highly efficient. Meanwhile, it has to furnish the best power gain at the minimal area overhead. A metal zig-zag antenna has been demonstrated to have these criteria [14]. Furthermore, this antenna also provides negligible effect of rotation on received signal strength, hence making it the most appropriate candidate for WiNoC application [15]. Figure 2 shows the detail of the zig-zag antenna structure.

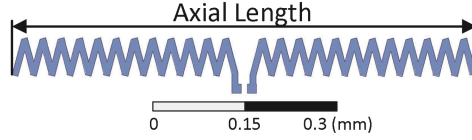


Figure 2. The zig-zag antenna [5]

2.2 Wireless Transceiver Architecture

The low power design of wireless transceiver is the pivotal factor to ensure the desired performance in the WiNoC system. For that reason, low-power design considerations were taken into account for both architecture and circuit levels of the transceiver. As depicted in Figure 3, a generic WiNoC OOK transceiver composed by a transmitter and a receiver that share the same antenna by means of a RF-switch. As shown in figure, a token controller is present to assure that the wireless channel is not busy at the moment of a transmission. If the channel is free incoming flit will be converted in a serial fashion by mean of the serializer. The main task of transmitters consists in adapting the data incoming from the electrical medium to the wireless medium by means of an antenna. In particular, a transmitter is constituted by a serializer, which converts parallel streams of data (flits) in a serial fashion. An OOK modulator converts data in higher frequency signal that will be delivered to the antenna via a power amplifier (PA). The structure of the receiver is the opposite of the transmitter. Radio frequency signals will be converted in a baseband stream of data with a demodulator. A deserializer converts a serial stream in to a flit.

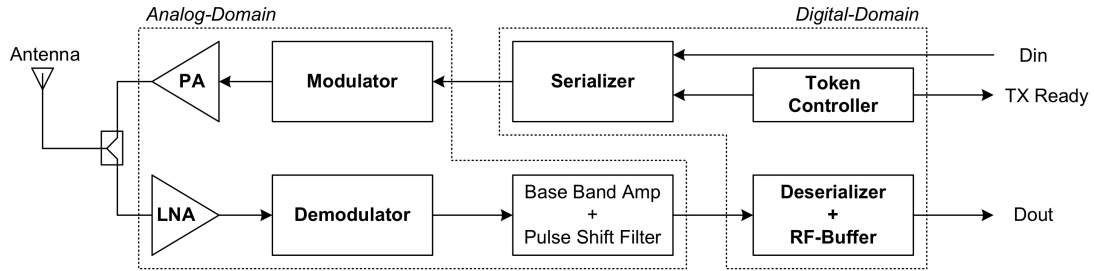


Figure 3. OOK WiNoC transceiver [16]

3. EXPERIMENTAL SETUP

The evaluation between NoC and WiNoC architectures employed a cycle-accurate systemC based simulator called Noxim [1]. Mesh-based topology is chosen because of its natural layout easily map to an IC. In addition, due to its physical regularity this network is also scalable and adaptable with simple routing algorithm. In order to identify how the architectures reacts in different conditions, the simulation are carried out under various traffic scenarios namely hotspot, transpose and random. Simulations have been done for three network scales namely 8×8 (64 nodes), 16×16 (256 nodes), and 32×32 (1024 nodes). Table 1 shows the simulation setup, while the traffic descriptions are shown in Table 2.

Table 1. Simulation Setup

Parameter	Descriptions
Network Sizes	8×8 , 16×16 , 32×32
Number of Radio Hub	4×4
Number of Channels	8
Simulation Time	100 000
Technology	65 nm
Clock Frequency	1 GHz
Switching Mechanism	Wormhole
Radio Access Control	Token Packet
Flit Size	32 bits
Routing Algorithm	XY, west-first, north-last, negative-first, odd-even, DyAD
Wireless Data Rate	16 Gbps
Wireless Communication	millimeter-wave

Table 2. Traffic Patterns

Pattern	Descriptions
Random	Uniform distribution of traffic from source to destination where each node sends packets to others with the same probability.
Transpose	Bit-permutation traffic adopting transpose matrix.
Shuffle	Bit-permutation traffic from source to destination with shifted order address.

For different cases of traffic distribution, the experiments are carried out based on 8×8, 16×16, and 32×32 network sizes. The large size up to 32×32 (1024 cores) WiNoC is chosen to investigate the impact of radio hub allocation and placement for WiNoC architecture in handling large network. As previously mentioned, the comparative analysis between WiNoC and mesh NoC are made in terms of global average delay, network throughput and energy consumption.

4. RESULTS AND ANALYSIS

4.1. Effects of Routing Algorithm

Routing is the procedure that is employed to deliver the flits onward to the sentence directions over the network between from the source to its destination. The performance of NoC and WiNoC architecture have been evaluated with the popular different routing scheme namely XY, west-first, north-last, negative-first, odd-even and DyAD. The selection behind of these routing algorithm are because they are based on wormhole switching mechanism that provide deadlock and livelock freedom in the two-dimensional mesh topology [17]. Figure 4 shows how the performance of the NoC and WiNoC architecture with respect to network load for 16 x 16 mesh under transpose traffic pattern. The rationale behind the selection of this non-uniform traffic is because its practicality for the real world application.

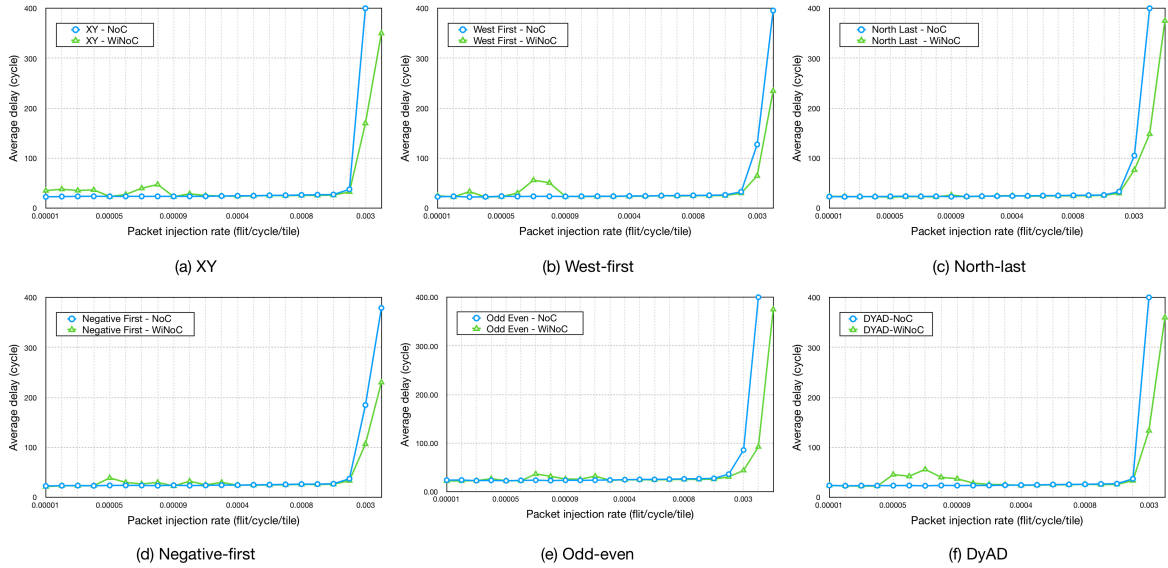


Figure 4. Comparative performance evaluation between NoC and WiNoC architecture under different routing algorithm

As the whole observation, from performance perspective WiNoC beats NoC architecture in all routing schemes. In particular, WiNoC is able to achieve higher saturation throughput compared to WiNoC. For instance, as can be seen in Figure 4(e) WiNoC has more capability in handling more network load in odd even routing algorithm which has the saturation point at 0.005 instead of 0.003 for NoC mesh. The reason of this is due to in the odd-even routing scheme, some turns are prohibited only in even column meanwhile some other turns are restricted in odd column. Hence, the degree of adaptiveness offered by this scheme is higher than others scheme.

4.2. Effects of Network Size

To investigate the effect of network size in both architectures, three various network sizes (64, 256 and 1024 nodes) have been simulated under numerous traffic distributions as described in Table 2. Odd-even routing scheme were adopted due to its advantage in handling more network load as has been explained in Section 4.1. This routing is utilized in the wired NoC layer until a wireless node with radio hub is found. Flits are then sent to its destination through the one-hop wireless channel.

4.2.1. Impact on Packet Injection Rate

Saturation throughput can be defined as the network throughput at which packet injection rate (PIR) begins to saturate. It is a common metric utilized to evaluate network performance [3]. At this point of network saturation throughput, the system is not effective in handling the network loads anymore. When PIR is set to 0.001, the rate of injection is 1 packet for every 1000 cycles. Since packets are set to 32 flits size, hence it resulted in 0.0032 flits/node/cycle, which corresponds to 0.001 packet/node/cycle of throughput. Figure 5 summarizes the comparison on the network latency of two simulated architectures namely mesh-NoC and WiNoC under different traffic load distributions as we vary the network dimensions.

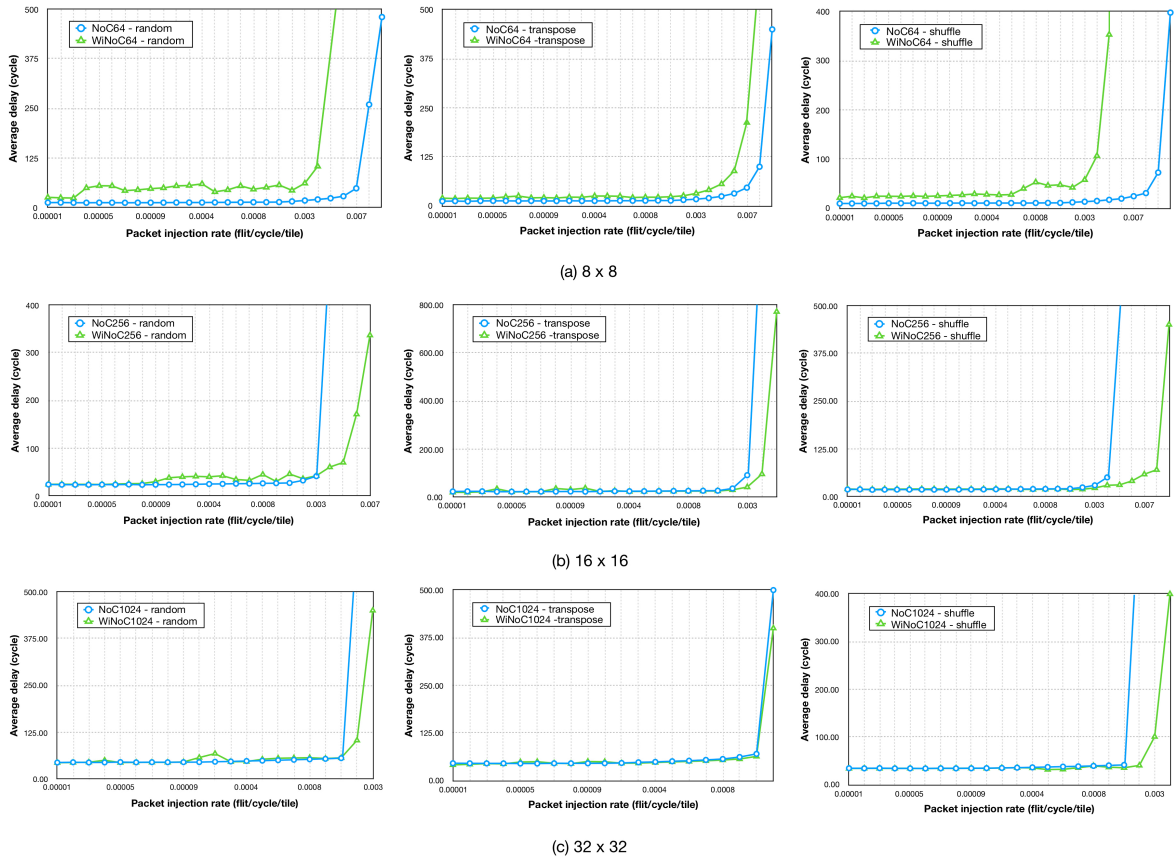


Figure 5. Global average delay comparisons for various network sizes under different traffic load distributions

The latencies for both architectures are almost identical for all scenarios of traffic patterns and network sizes at low network commitment. However, as the network load increases, the latency of network begin to exponentially increase depending on traffic patterns and system sizes. In general, an architecture that has higher PIR demonstrates a better system because of its ability to manage higher network loads. For instance, in Figure 5(a), at transpose traffic WiNoC saturates at PIR 0.007 compared to NoC at PIR 0.009 has reveals that NoC has better performance in 8x8 system size. In contrast, Figure 5(b) for transpose distribution shows 16x16 WiNoC architecture is saturated at higher PIR, 0.006 compared to 0.004 for NoC which indicates that WiNoC has more desirable performance. Overall, from the network size perspective WiNoCs have disadvantages in 8x8 topology scale. In the contrary, as the topology scale become bigger (16x16 and 32x32) WiNoCs were shown to have more fitting performance due to the factor of radio hub that assist in single-hop long distance wireless communication.

4.2.2. Impact on Network Throughput

Throughput is another important metric indicator of the performance and quality of a network connection. It can be defined as how the network is able to process the requested packet injection rate and can be represented as flits/cycle. A high ratio of unsuccessful packet delivery will lead to lower throughput and degraded performance. Network throughput is affected by a number of factors such as network congestion and packet loss. Hence, the higher the throughput in the network reflects to more effective system.

Figure 6 shows the network throughput comparisons for various network sizes (8×8 , 16×16 and 32×32) under different case of traffic scenarios. As illustrated in transpose traffic, bigger network WiNoC256 and WiNoC1024 have 6.36% and 1.82% respectively higher throughput in comparison with the conventional NoC architecture. The reason for this is the ability of the bigger system architecture that can cope with higher networks load as has been discussed in the impact of PIR in Section 4.2.1.

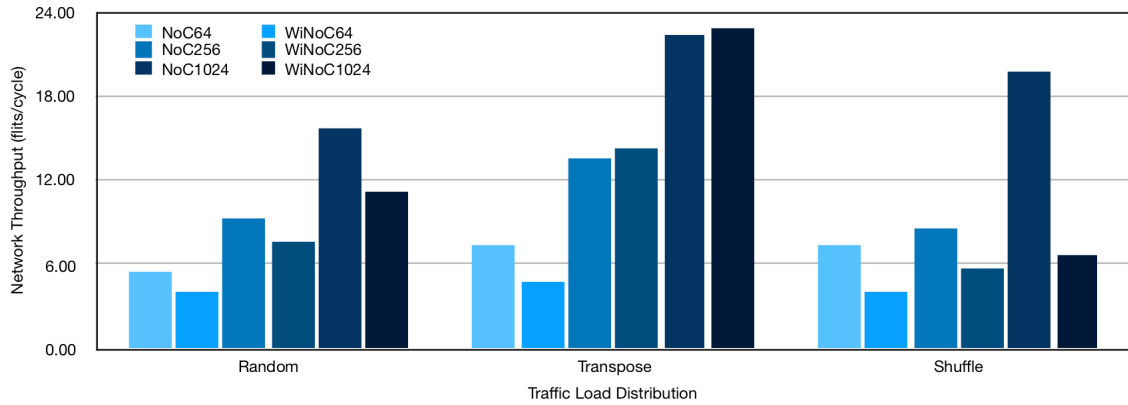


Figure 6. Network throughput comparisons for various network sizes under different traffic load distributions

4.2.3. Impact on Energy Consumption

The reduced energy consumption leads to a better power characteristic in the system architecture. Figure 7 shows the energy comparisons between NoC and WiNoC for varied network sizes subject to different type of traffic patterns. As can be observed, the energy consumption has an incremental trend as the network increase in size. In addition, WiNoCs utilized more energy consumption for all cases networks sizes and traffic distributions.

This is due to the wireless communication activities introduced by on-chip transceivers in WiNoC composition. On the other hand, wireless radio hubs routers are more energy-hungry than conventional NoC routers. From the context of network size, as in transpose traffic for example when network topology grows bigger WiNoC consume lower energy consumption reduced from 87% (8×8), 63% (16×16) to 27% (32×32). This revealed that WiNoC benefited in energy saving when the network size is larger. The factor of this savings is due to the least wireless utilization of the radio hub in the bigger WiNoC as described in Section 4.2.4.

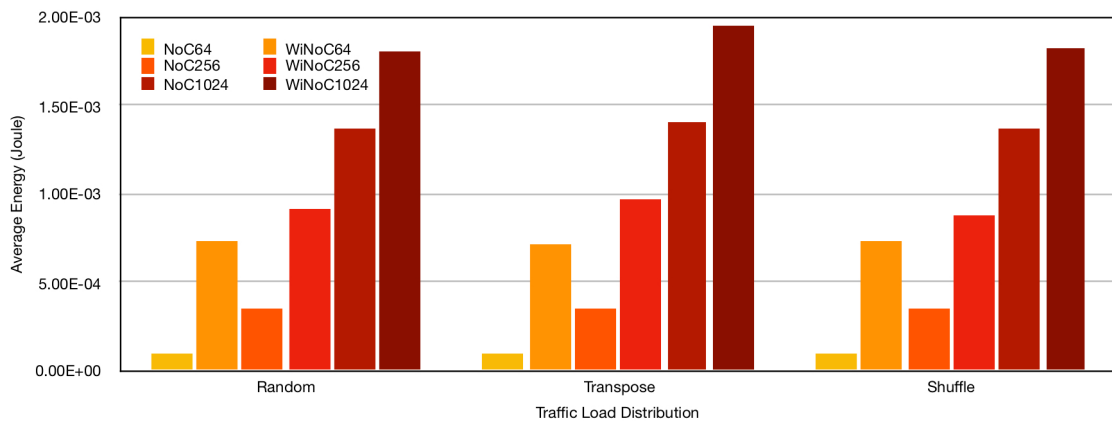


Figure 7. Energy consumption comparisons for various network sizes under different traffic load distributions

4.2.4. Impact on Wireless Utilization

The considered traffic settings (uniform random, transpose and shuffle) allow the network to work in different regions characterized by a different utilization of the wireless medium. In particular, wireless utilization can be defined as the ratio between the number of communications that use, totally or in part, the wireless medium and the total number of communications [18]. As shown, the percentages of wireless utilization are inversely proportional with system size.

The high percentage (on average 86%) of wireless usage in 8×8 is because of the dense distributions of 16 radio hubs in 64 nodes WiNoC. In the contrary, for biggest network (32×32) from this experiment resulted in low percentage (on average 3%) of wireless usage due sparse distribution of the radio hubs. Optimally, the 16×16 network architecture give the most suitable concentration that use on average 27% wireless utilization. This is practical since the radio hubs were used for the purpose of long distance communication. Hence, this justifies the reason why 256 nodes give the best results in terms of performance as well as network throughput.

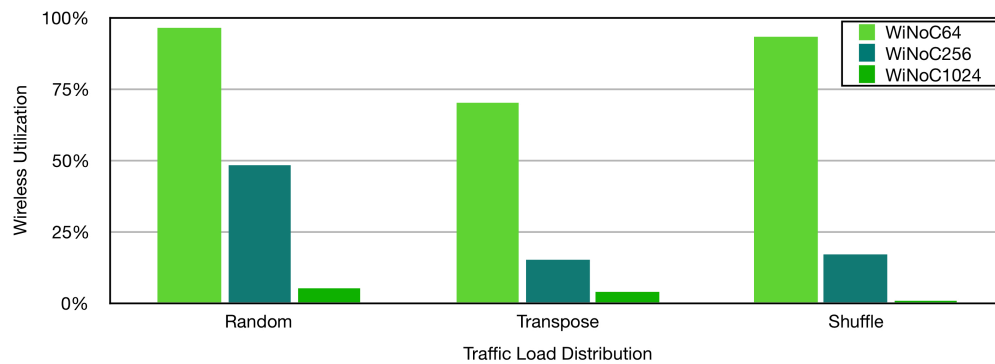


Figure 8. Percentage of wireless utilization for different size of WiNoC architecture under various traffic distributions

5. CONCLUSION

The objective of this research is to investigate the impacts of different routing strategy and the effects in varying the number of network sizes between the classical mesh NoC and WiNoC architecture. From experimental results, can be concluded that WiNoC architecture performs its best among other topology at 16×16 network size in nonuniform transpose traffic with better average speedup ($\sim 1.2 \times$) and improved network throughput by 6.36%. However, it has the trade-off on higher energy consumption in comparison with conventional mesh NoC. For future work, we target to look into the implication of the number radio hub placements on several specific WiNoC architectures such as iWise, WCube and McWiNoC.

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