A Parameterizable Channel Model for Wireless Networks-on-Chip Design

Michael Opoku Agyeman
Department of Computer and Immersive Technologies, University of Northampton, UK.
Email: Michael.OpokuAgyeman@northampton.ac.uk

***Abstract*—To alleviate the performance degradation due to the slow non-scalable wirelines in conventional Network-on-Chip Wireless Networks-on-Chip (WiNoCs) have emerged as a promising solution. However, on-chip communication poses several constraints on the wireless layer. Hence, there is the need for simulation and design tools that consider the effect of the wireless channel at the nanotechnology level. In this paper, we present a parameterizable channel model for WiNoCs which takes into account practical issues and constraints of the propagation medium. The proposed channel model demonstrates that total path loss of the wireless channel in WiNoCs suffers from not only dielectric propagation loss (DPL) but also molecular absorption attenuation (MAA) which reduces the reliability of the system.**

I. Introduction

Wireless Network-on-Chip (NoC) has been proposed as a more promising solution to these issues and has gained the attention of many researchers in this field of study [1]. WiNoCs adopt mm-Wave enabled routers and packet or circuit switching to handle data communication in a multi-core system. Recent research shows that WiNoCs outperforms its more conventional wired counterpart [2] with low power consumption and reduced latency between remote cores. However, WiNoC is still in its infancy and several challenges are currently being addressed to facilitate its acceptance as a mainstream interconnect fabric and bridge the widening gap between computation complexity and communication efficiency for emerging SoC design [1]. Particularly, new design evaluation tools must account for the constraints imposed by the wireless interface. Compared to wireline NoCs, the critical difference is the model of wireless propagation channel in WiNoCs.

In order to more accurately simulate and evaluate the actual performance of system, a wireless propagation channel model is required. In this paper, We propose a parameterizable wireless channel model to evaluate the losses in emerging WiNoCs. Considering both line-of-sight and reflective transmission in traditional WiNoCs an on-chip reflection channel model which accounts for the transmission medium and built-in material of a practical chip is developed. Simulation results of the proposed channel model reveals that, the performance degradation due to separation distance between on-chip antennas is higher with low reliability compared to a conventional channel modeled over DPL space. We demonstrate that, the total path loss of the signal transmission consists of both dielectric propagation loss (DPL) and molecular absorption attenuation (MAA). As a second contribution of the paper, we evaluate the effects of the medium compositions within the chip package on the total noise temperature of a WiNoC. The noise temperature and path loss model caused by the molecular absorption are shown to have a significant impact on the capacity of the WiNoC. It is also observed that transmission along the wireless channel in WiNoCs is less efficient compared to conventional wireless channel model with no MAA, even when the transmission distance between two antennas is very small.

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II. On-Chip Wireless Signal Propagation

In order to understand the reduction in performance of WiNoCs due to the reliability issues of wireless channel, it is important to characterize the traditional mm-Wave transmission channel for on-chip wireless communication.

Fig. 1 illustrates a typical WiNoC architecture where two cores $\mathcal{C}_\mathcal{T}$ and $\mathcal{C}_\mathcal{R}$ the transmitter and receiver cores, respectively, communicate via mm-Wave channel. Here, we consider a metal cube enclosure as the package with a longest rectangular side of d_C and a height of $h \ll d_C$. Let h_T and h_R denote the height of the mm-Wave antennas (zigzag antennas) at $\mathcal{C}_\mathcal{T}$ and $\mathcal{C}_\mathcal{R}$, respectively. The material property of the transmission medium between $\mathcal{C}_\mathcal{T}$ and $\mathcal{C}_\mathcal{R}$ is assumed to be time-invariant over the transmission of a data frame and changes independently from one frame to another. For simplicity, we consider quasi-static channel model in this work. Let d denote the distance of separation between $\mathcal{C}_\mathcal{T}$ and $\mathcal{C}_\mathcal{R}$. Accounting for chip floorplanning and hence in order to avoid the placement of the cores on/near the edges of the package, d should be less than $d_{\max} = d_C\sqrt{2}$. To accurately model the wireless channel interface of existing WiNoCs, the absorption and resonance of the medium compositions within the chip package should be taken into account, especially in the high frequency band of modern multi-core design. Specifically, various molecules and their isotopologues may cause molecular absorption attenuation (MAA) at various frequency bands [3]. Therefore, the signal transmission between $\mathcal{C}_\mathcal{T}$ and $\mathcal{C}_\mathcal{R}$ in Fig. 1 suffers from the path loss caused by not only the dielectric propagation loss (DPL) but also the MAA.

For convenience, the main notation and the well-known constants used in this paper are listed in Tables I and II, respectively.

III. Proposed Wireless Channel Model

We evaluate the wireless communication fabric for existing WiNoC. Unlike the conventional channel models for the macro-world, on-chip communication introduces new constraints and challenges. Hence in order to study the effect of the wireless channel on the performance of on-chip communication, we propose a channel model that considers the physical dynamics of multi-core communication. In the proposed

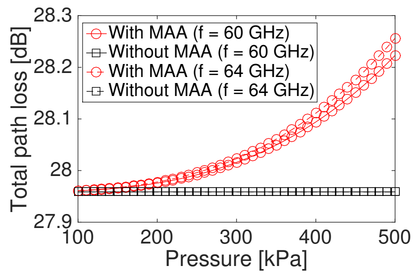

Fig. 3. Total path loss versus ambient pressure at different frequencies.

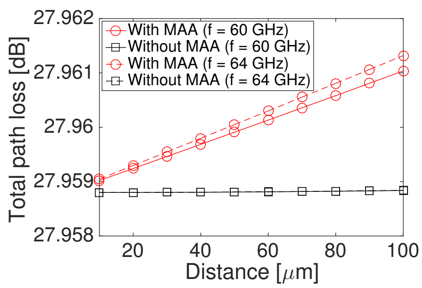

Fig. 4. Total path loss versus distance between mm-Wave antennas at different frequencies.eps

Fig. 3 plots the total path loss of various channel models versus the ambient pressure (i.e. p in kPa[2]) applied on the chip package. It can be seen in Fig. 3 that the total path loss in the conventional channel model is independent of the ambient pressure. However, the total path loss in the proposed channel model for practical WiNoC is shown to exponentially increase as the ambient pressure increases, which confirms the claim of the exponentially increased total path loss over the ambient pressure in Remark 2. Considering the impacts of distance between two cores on the performance of WiNoC, in Fig. 4, the total path loss of various channel models is plotted. We consider the transmission distance between $\mathcal{C}_{\mathcal{T}}$ and $\mathcal{C}_{\mathcal{R}}$ (i.e. d) with respect to two values of frequency $f = 60$GHz and $f = 64$GHz. The distance d is assumed to vary in the range $[10 : 100]\mu$s and the other simulation parameters are similarly set as in Fig. 2. It can be observed that the total path loss in both the proposed and the conventional channel models increases as the distance increases, which could be straightforwardly verified from the path loss expression in (16). However, there is only a slightly increase of the path loss in the conventional model at the GHz frequency band, while such increase is shown to be significant with a much higher path loss in the proposed channel model, which is in fact caused by the consideration of the MAA to reflect the practical WiNoC. We investigate the impacts of MAA in the proposed channel model on the achievable channel capacity of WiNoCs. Fig. 5 plots the channel capacity against the distance between two cores $\mathcal{C}_{\mathcal{T}}$ and $\mathcal{C}_{\mathcal{R}}$. Similarly, two channel models including the proposed and the conventional models are considered for comparison and the parameters are set as in Fig. 4. The antennas are assumed to operate at frequency $f = 60$GHz. As shown in Fig. 5, the channel capacity in the proposed channel model for the practical WiNoCs is lower than that in the conventional channel model, even when the distance between two cores is less than 0.01mm. This observation can be intuitively verified through the impacts of the transmission distance on the total path loss.

[2]Note that 1atm = 101.325kPa

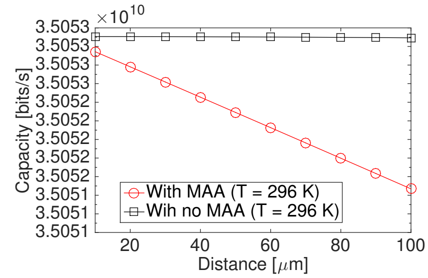

Fig. 5. Channel capacity versus distance between two antennas.

V. Conclusion

In this paper, we have proposed a channel model for WiNoCs, operating in the GHz band, which accounts for the on-chip constraints. It has been shown that MAA has a considerable effect on the reliability of WiNoCs. Moreover, the total path loss has been shown to exponentially increases as the ambient pressure applied on the chip increases. Additionally, the total path lose increases as the distance between two cores increases which increases the number of erroneous transmissions in WiNoCs. Experimental evaluation reveals that a practical channel model for the wireless layer of WiNoCs have a lower channel capacity, which reflects the increased BER and reduced reliability of overall system at the GHz band.

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