Novel Hybrid Wired-Wireless Network-on-Chip Architectures: Transducer and Communication Fabric Design

[Extended Abstract]

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ABSTRACT

Existing wireless communication interface of Hybrid Wired-Wireless Network-on-Chip (WiNoC) has 3-dimensional free space signal radiation which has high power dissipation and drastically affects the received signal strength. In this paper, we propose a CMOS based 2-dimensional (2-D) waveguide communication fabric that is able to match the channel reliability of traditional wired NoCs as the wireless communication fabric. Our experimental results demonstrate that, the proposed communication fabric can achieve a 5dB operational bandwidth of about 60GHz around the center frequency (60GHz). Compared to existing WiNoCs, the proposed communication fabric can improve the reliability of WiNoCs with average gains of 21.4%, 13.8% and 10.6% performance efficiencies in terms of maximum sustainable load, throughput and delay, respectively.

1. INTRODUCTION

The slow multi-hop communication as well as poor scalability with technology of the conventional metal based interconnects has propelled the research for alternative communication fabrics for modern System-on-Chip (SoC) design [1]. Millimeter-wave has been investigated as a suitable candidate with promising CMOS components that can scale with transistor technology. Traditional wire based NoCs on the other hand, are highly efficient for short distances despite their limitations over long distance. Consequently, hybrid wired-Wireless Networks-on-Chip (WiNoCs) have emerged to combine wireless millimeter wave (mm-Wave) and wired communication fabric in NoCs. However due its 3-D free space signal radiation the wireless communication fabric is lossy and hence lowers the overall reliability of WiNoCs. Conventional wires have extremely low bit error rate (BER) of around 10^{-14} compared to that of mm-Wave (around 10^{-7}). In NoCs, a single message loss can have drastic effects on the performance of the multi-core system. Hence, novel wireless communication fabrics that offer high data bandwidth as well as improved reliability with BER similar to the wired communication fabric are required to provide a good trade-off for WiNoCs. 2-D guided wave in the form of surface wave (SW) interconnect is an emerging wireless communication fabric that is power efficient and has a highly reliable data throughput for long distance communication [2]. However, previous contributions on SW have not focused on optimizing the communication fabric to improve reliability wireless interface [2]. We propose a highly reliable SW communication fabric along with an efficient transducer interface that is able to match the signal integrity of short range wired NoCs.

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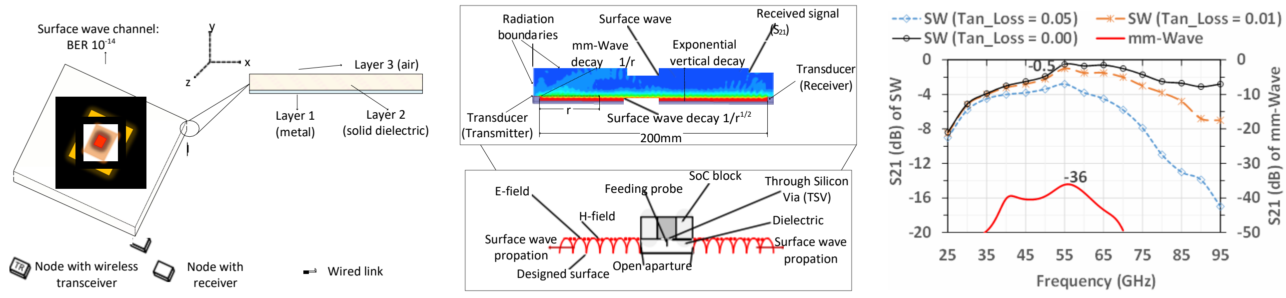
2. DESIGN OF RELIABLE CMOS-BASED 2-D WAVEGUIDE FOR WINOCS

We replace the wireless channel with a reliable 2-D communication fabric which radiates signals in the form of surface waves as shown in Fig 1(a). Transverse Magnetic mode *(TM)* surface wave can be supported by a dielectric-coated metal surface. To enable the field concentration in Layer 2 nearer to the surface of Layer 1 for TM-surface wave propagation, a positive surface reactance is required. The surface reactance, X_s is given by:

$$X_s = 2\pi f \mu_0 \left(\frac{E_r - 1}{E_r} l + \frac{\nabla}{2} \right) \tag{1}$$

It can therefore be deduced from Eq. 1 that, the efficiency of the TM surface wave propagation depends on the operating frequency, f, dielectric constant, E_r, thickness of the dielectric material, l, and the skin depth of the metal conductor, ∇ To generate an efficient TM surface wave signal in a 2-D waveguide sheet, we use commercially available low loss cost-effective laser ablatable Taconic $RF-43$ material [3] with 0.2mm thickness as the dielectric (Layer 1 in Fig. 1(a)). By introducing the 0.25mm thick Taconic material, we can achieve a surface reactance X_s of 30Ω to 150Ω over the wide frequency range of 20GHz to 100GHz for TM mode surface wave. The designed transducer consists of a parallel waveguide fed by a quarter-wavelength monopole through an open aperture. The transducer is coupled to a transceiver circuit which is responsible for modulation, signal transmission and receiving capabilities. We adopt the low-power non-coherent on-off keying (OOK) modulator for our implementation (Fig. 1(b)) which has been demonstrated to achieve a BER less than 10^{-14} [4]. We have performed simulations in Ansys HFSS. As shown in Fig. 1(b), the electric field distribution demonstrates that a high percentage of the



(a) (b) (c)

Figure 1: Proposed wireless communication fabric for WiNoCs. In Fig. 1(a) a dielectric-coated plane surface with a loss tangent *tan* δ is used. Fig. 1(b) shows transceiver and transducer (inverted quarter-wavelength monopole) components stacked over the CMOS-based 2-D waveguide sheet [2]. Fig. 1(c) represents the simulated S_{21} (dB) over wide-band frequency on the reactive surface with different lossy dielectric materials

transmitted signal is successfully launched into the surface. Across the long distance separation of 200mm, a near constant electric field distribution is achieved. Also the electric field decays exponentially away from the implemented surface, indicating that surface wave is successfully launched and received with a high signal efficiency. Fig. 1(c) shows that, the reactive surface appears to have a flat response over a wide frequency range and has a 3 dB bandwidth of almost 45GHz (from 30GHz to 75GHz with Tan_Loss = 0.01), and a 5dB bandwidth of almost 60GHz (from 30GHz to 87GHz with Tan_Loss = 0.01). On the other hand, the S_{21} of mm-Wave (two zigzag antennas separated by 20mm) is around -36dB which is significantly lower than that of the proposed communication fabric. Therefore, the proposed communication fabric is able to successfully excite and transmit high frequency-high bandwidth surface wave signals with high reliability (S_{21} of 0 to -2dB).

3. EXPERIMENTAL RESULTS

Cycle-accurate experiments are performed using an extended version of Noxim simulator with a setup as summarized in Table 3. We adapt the BER and the S_{21} of the communication fabric as the error model (mm-Wave: 10^{-7}, wire: 10^{-14}, SW: 10^{-13}). Fig. 2 shows the aver-

Table 1: Simulation setup

width of NoC buffer and Links	16 Byte width
Transceiver nodes	5 evenly distributed
FDMA carrier frequencies	128
Tile dimensions	$3.6 \times 5.2mm^2$
Processing element	Two Pentium class IA-32 cores
cache	Two 256 KB private L2 caches

age performance improvement of wired-SW over mm-Wave WiNoC in terms of saturation load, average packet latency and throughput of various NoC configurations under random traffic pattern with west-first routing and random selection method. In general, wired-SW improves the maximum sustainable load, average packet latency and throughput by an average of 20.9%, 10.7% and 13.8% compared to mm-Wave even when small number (4 to 6) of wireless transmitting nodes are used.

4. CONCLUSIONS

We propose a CMOS based 2-D waveguide communication fabric in the form of surface wave that improves the reliability of the wireless communication channel in WiNoCs. A

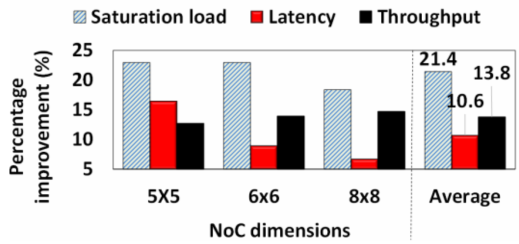


Figure 2: Average percentage improvement of wired-SW over mm-Wave WiNoC of varied VCs (2, 4 and 6) and buffer sizes (4, 6, 8, 10, 18)

thin metal layer coated with Taconic RF-43 dielectric material is designed as the 2-D wireless communication medium. A low noise quarter-wave transducer is proposed as the interface between the SoC blocks and the wireless interface. HFSS results show that, the proposed transducer has a significantly high bandwidth (45GHz - 60GHz). Cycle-accurate simulations results show significant reductions in the average packet delay and power consumption compared to millimeter wave hybrid wired-wireless NoCs.

5. REFERENCES

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