On-Demand SIMO Channel Impulse Response Shaping in Smart On-Chip Electromagnetic Environments

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ABSTRACT

We recently introduced the concept of reconfigurable Wireless Networks on Chips (r-WNoCs) for which an on-chip reconfigurable intelligent surface (RIS) endows the wireless on-chip propagation environment with programmability. In this work-in-progress report, we apply this idea to a single-input multiple-output (SIMO) context. Specifically, we demonstrate that using an on-chip RIS we can simultaneously shape multiple channel impulse responses (CIRs) such that they become essentially pulse-like despite rich scattering inside the chip enclosure. Pulse-like CIRs are essential to enable high-speed information exchange between different processors on the same chip with the simple on-off-keying modulation schemes envisaged for WNoCs.

CCS CONCEPTS

• **Hardware** → **Radio frequency and wireless interconnect**.

KEYWORDS

Over-the-Air Equalization, Wireless Network-on-Chip, Software-Defined Metamaterial, Reconfigurable Intelligent Surface, ISI Mitigation, SIMO

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1 INTRODUCTION

Wireless networks on chip (WNoCs) are a candidate technology to overcome the current computation-speed bottleneck of multi-core chips: information exchange between cores via wired interconnects [5, 7, 12]. WNoCs, however, face their own challenges: because the chip enclosure constitutes a rich scattering environment, either the path loss is large such that the channel impulse responses (CIRs) are pulse-like but associated with very low received signal strength indicators (RSSIs), or the path loss is low but the CIRs suffer from strong multipath [1, 15]. The latter is problematic because WNoCs are restricted to simple on-off-keying (OOK) amplitude modulation such that in the presence of multipath the transfer speed must be curbed to prevent inter-symbol interference (ISI). Recently, we demonstrated that a programmable on-chip electromagnetic environment can potentially overcome this RSSI-ISI dilemma [11]. By integrating a programmable metasurface into the chip enclosure's ceiling, the scattering properties of the on-chip wireless environment can be programmed on demand. By tailoring the interference of different paths, we proposed in Ref. [10] and showed in Ref. [11] that the CIR between a pair of antennas can be shaped such that it is essentially pulse-like. The physical mechanisms at play are well understood from programmable indoor environments at the meter scale [2, 9], and the feasibility of the idea was experimentally demonstrated at the indoor scale in Ref. [9]. More recently, RIS-based spectral channel shaping for ISI mitigation ("over-the-air equalization") has also been studied from a signal processing perspective under various assumptions about the nature of the multi-path scattering [3, 4, 16, 17].

A significant motivation for WNoCs is, however, their broadcast ability, motivating the investigation of simultaneous multi-CIR shaping in such reconfigurable WNoCs (r-WNOCs). In this work-in-progress report, we consider the transfer of information from one transmitter to three receivers on a multi-core chip, a classic single-input multiple-output (SIMO) scenario.

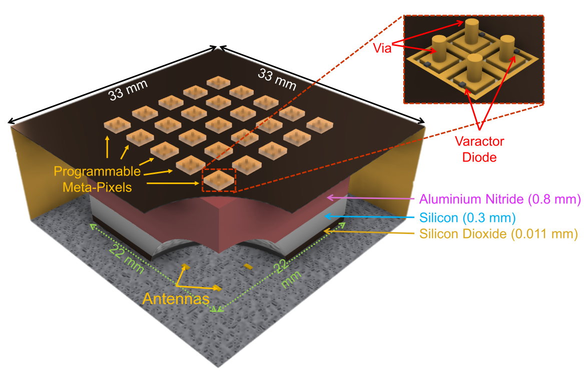

Figure 1: Considered prototypical multi-core chip architecture involving multiple antennas and a programmable metasurface integrated into the package ceiling. [Adapted from Ref. [11].]

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2 METHODS

We study the above-outlined SIMO problem in full-wave simulations of a simplified prototypical chip architecture, following Refs. [10, 11, 15], and we use the on-chip design introduced in Refs. [10, 11] based on mushroom-like meta-atoms [13, 14]. The tunability mechanism relies on a varactor diode, but we restrict ourselves to 1-bit tunability in the following. A schematic drawing of this setup is reproduced in Figure 1 and the reader is referred to the mentioned references for further technical details.

We consider an r-WNoC in the typical 60 GHz regime in which one antenna emits and three antennas are the dedicated simultaneous receivers, meaning that three CIRs should simultaneously be pulse-like. This is in contrast to the results from Ref. [11] in which each on-chip RIS configuration only targeted one specific CIR. The problem of SIMO CIR shaping has also not been studied at the indoor scale: Ref. [9] studied SISO CIR shaping and Ref. [8] studied MIMO single-frequency channel matrix shaping.

Unlike in (quasi) free space [6], in rich-scattering environments no analytical expression for the impact of the RIS configuration on the wave field exists due to the complexity of the problem. Our procedure to identify the optimal on-chip RIS configuration is an iterative optimization similar to Ref. [11] but differs in the fact that we now have multiple simultaneous metrics that are to be optimized. For each of the three considered CIRs, we would like to simultaneously impose a pulse-like shape and at the same time achieve the highest possible channel gain. In our preliminary study, we weighted these different constraints by visual inspection at each iteration step.

Given the static and shielded nature of the on-chip wireless environment (the metallic chip enclosure acts like a Faraday cage), the optimization of the on-chip RIS configuration has to be performed only once per considered traffic scenario in a calibration step. At run time, one can then switch dynamically between different optimized configurations from the established library to adapt to instantaneous traffic needs, meaning that the configuration optimization involves no cost at run time.

3 RESULTS

The optimized on-chip RIS configuration obtained after the iterative procedure is displayed in Figure 2. The fact that seemingly more elements are in the 1 pF state than in the 0.1 pF state should be understood as a coincidence. On average, there is no reason why one state should be more frequent than the other [11]. We also note that the pattern of the optimal configuration is not intuitively understandable because it depends on the rich scattering properties of the chip enclosure as well as the antenna locations.

In Figure 3, we plot the the corresponding CIR profiles for the three considered wireless links. In red, we show the envelopes of 32 CIRs corresponding to random RIS configurations. Strong multipath components are visible in particular for the second and third CIR. OOK-based communication would have to operate with curbed transmission rate to avoid ISI.

The black curves in Figure 3 indicate the CIR profile corresponding to the optimized on-chip RIS configuration from Figure 2. As desired, multipath components are significantly suppressed in comparison to the red CIR profiles. However, we note that the optimized

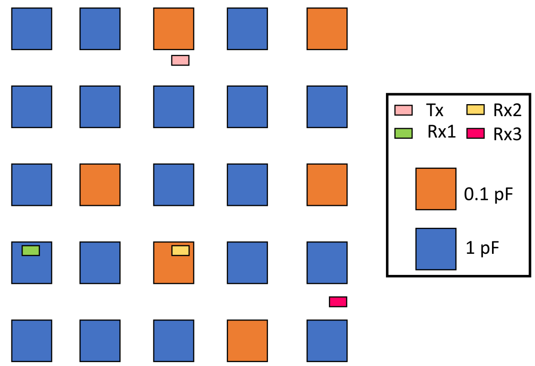

Figure 2: Optimized 1-bit on-chip RIS configuration after one optimization loop. The location of transmitting (Tx) and receiving (Rx) antennas is also indicated.

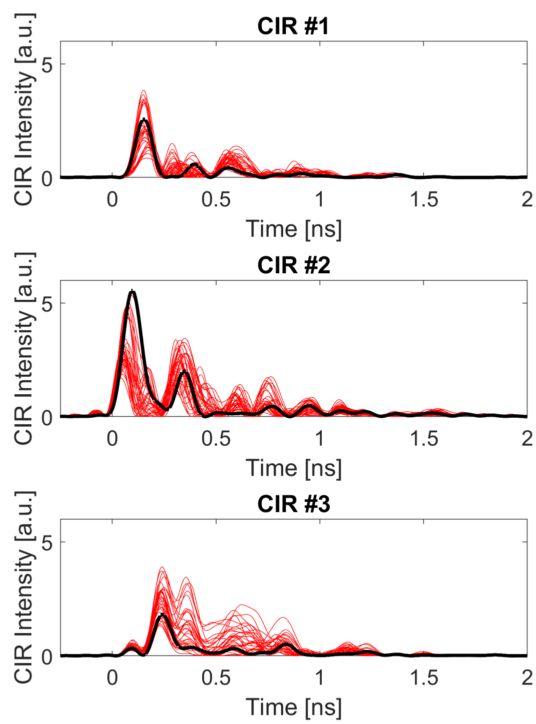

Figure 3: On-chip SIMO CIR shaping. The three panels show the three considered CIRs. Red lines display 32 random CIRs obtained with random configurations of the on-chip RIS. The thick black line indicates the CIRs corresponding to the optimized RIS configuration intended to yield pulse-like CIRs.

CIR profiles are imperfect: a non-negligible second peak remains for the second CIR, and the third CIR now suffers from notably higher path loss.

Nonetheless, the benefits of a smart on-chip electromagnetic environment for CIR shaping are evident also for SIMO scenarios.

Our results can be expected to improve further with refined optimization algorithms as well as the use of more meta-atoms with multi-bit programmability.

4 OUTLOOK

This work-in-progress paper summarizes our on-going effort to explore the potential of r-WNoC, here for the case of SIMO scenarios. Looking ahead, we intend to use more communications-oriented optimization metrics such as the bit-error-rate.

Future work will also include a rigorous comparison of the presented results with a conventional WNoC scenario in which the on-chip RIS is absent. This comparison is non-trivial because (i) the on-chip RIS alters the chip enclosure's reverberation time by adding absorption (see Ref. [11]), and (ii) a given link in a conventional WNoC can only be studied in one specific realization of the wireless environment which is likely not representative of the underlying statistics (see Ref. [9]).

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