Verification of an Evaluator for a New-Radio Channel Estimator

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***Abstract*—In this paper, we develop a flexible framework for the evaluation of a channel estimator and verify it against an analytical solution of the frequency response of ideal phased array hardware components. This evaluator is necessary to support future work in the evaluation of a new Monte-Carlo based channel estimator for 5G wireless communication devices. This new channel estimator will provide more accurate channel estimation by accounting for hardware irregularities.**

I. Introduction

As Fifth Generation (5G) communications evolve, the hardware is extending to millimeter-waves (mmWaves) and electrically large phased array architectures to achieve greater data throughputs. Combined with modulation and multiplexing techniques like quadrature amplitude modulation (QAM) and orthogonal frequency division multiplexing (OFDM), 5G hardware requires extensive analysis to understand its non-ideal hardware performance. Current 5G NR (New-Radio) OFDM simulations [1,2] concentrate on higher layers in the communication stack. These techniques do not focus on evaluating channel estimators by quantifying metrics such as mean squared error (MSE) between the actual and estimated channel which provide an unabstracted calculation of estimator accuracy. There are also many commercial software suites that have similar capabilities [3], but none provide an open source solution necessary for custom features and computational efficient analysis at a reasonable cost.

In this paper, we present the design and verification of a channel estimator evaluator. This evaluator emulates the physical layer of 5G OFDM communication devices and a propagation channel to assess the capability of a novel Monte-Carlo based channel estimator. Our evaluator leverages model-based simulation along with channel measurements. This model-based approach captures the effects of the hardware components' nominal responses and uncertainties on the channel estimator for mmWave phased array architectures. To provide testing in realistic channels, the evaluator also leverages synthetic aperture channel measurements from the National Institute of Standards and Technology (NIST) Synthetic Aperture Measurements with UnceRtainty and Angle of Incidence (SAMURAI) system [4]. This data allows us to evaluate channel estimators with measured synthetic aperture data and known hardware non-idealities. We calculate the mean squared error (MSE) between the actual and estimated channel response, error vector magnitude (EVM), and bit error rate (BER) as output metrics to evaluate an implemented channel estimator.

II. Channel Estimator Evaluator

Our evaluator is designed to provide flexibility in its configuration for rapid analysis of a channel estimator with a variety of different phased array hardware and propagation channels. Because of the frequency domain nature of OFDM, the evaluator described here assumes all components and channels operate in a linear regime. This results in a computationally efficient simulation to directly calculate the efficacy of a Monte-Carlo based OFDM channel estimator with added apriori assumptions. Fig. 1 shows the flow chart of the evaluator's operation of a single hardware configuration and propagation channel.

A. *Model-Based Hardware Approach*

The evaluator uses a model-based simulation to provide a modular software approach. This model-based simulation allows for quick and repeatable simulations with different hardware configurations by allowing hot-swapping of models without having to rewrite any simulation code. Each model defines the nominal response and the uncertainties associated with a hardware component. Different models representing the same type of component (e.g. models for two different phase shifters) have identical software interfaces, abstracting the different responses during simulation. The evaluator also leverages known propagation channels to test channel estimators. These propagation channels can be either simulated or measured with the SAMURAI measurements.

The combination of the hardware models and test channels enables the evaluation of a channel estimator in a wide variety of scenarios. The modular nature of the software permits any permutation of hardware models and propagation channels. Individual models can also be used in the evaluation to isolate

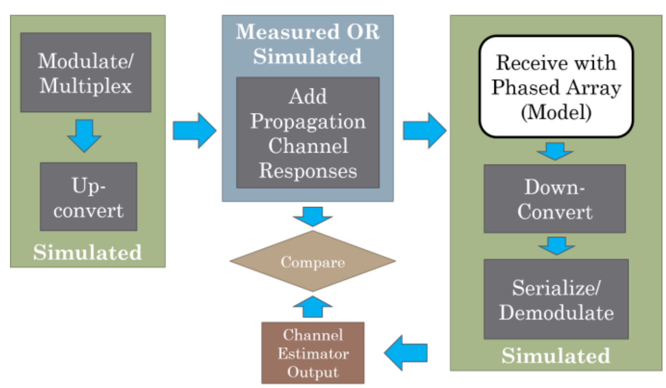

Fig. 1. Flow chart of the evaluator simulation.

the impact of single hardware components on a channel estimator under test. Combined uncertainty and bias from the nominal result is also calculated in each scenario.

B. *Design of a Model-Based Phased Array*

We designed a model-based phased array architecture to demonstrate the model-based approach, as seen in Fig. 2. This mmWave phased array architecture consists of phase shifters, amplifiers, and combiners. The hardware models are either described analytically using hardware component parameters (e.g., insertion loss and phase shift) or measured S-parameters with uncertainties.

C. *Synthetic Aperture Channel Measurements*

Measured test channels from the SAMURAI system replicate realistic propagation channels for estimator evaluation. The SAMURAI system utilizes an antenna (typically a horn or open-ended waveguide) mounted to a robotic arm and a vector network analyzer (VNA) to measure the frequency response of a propagation channel at different robot positions. These positions match the element locations of the array configuration used in the evaluator. These measurements are then loaded into the evaluator to calculate the angular frequency response of the channel for any given hardware configuration. The measurements are taken at a mmWave frequency band, (commonly at 27.5 GHz) as defined by the Federal Communications Commission (FCC) [5] and with a spacing of 15 kHz to cover all of the 3rd Generation Partnership Project (3GPP) subcarrier spacings in NR for the shared data channel [6].

III. Verification and Results

We verified the evaluator's performance against an analytical beamforming solution with an ideal plane wave test channel. The verification process uses the evaluator with "ideal" hardware models that have no loss, error, or phase discretization. This evaluator configuration was compared against the analytical based software used in [4]. Fig. 3 shows minimal mismatch (7×10^{-13} dB maximum) between the analytical beamforming software (Analytical) and the model-based approach (Evaluator) for a propagation channel with known incident angles.

Further steps are in progress to assess non-ideal hardware models. The spatial responses of non-ideal models are also compared against the analytical beamforming solution [3]. Another verification step compares the measured results of an integrated phased array against the expected result from the channel estimator evaluator.

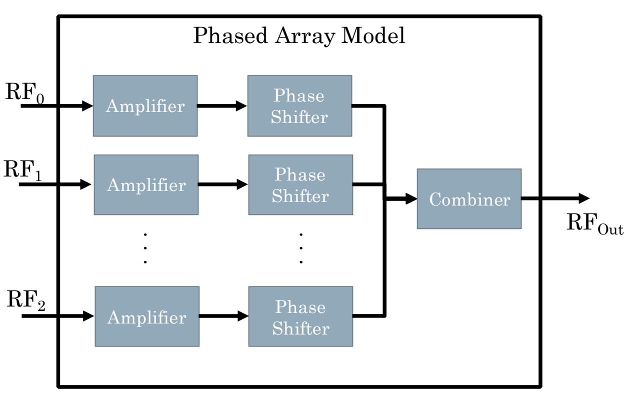

Fig. 2. Layout of a common phased array configuration.

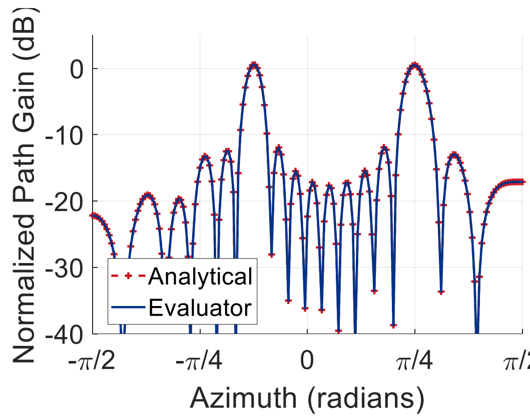

Fig. 3. Spatial responses of an analytical beamforming solution and the evaluator with ideal hardware models for known incident angles.

We also test modulation and demodulation of the evaluator using both simulated and measured channels alongside noise-free hardware models. For a least squares channel estimator, the MSE, BER, and EVM equal zero (omitting machine error), which agrees with the analytical solution for a static channel with no error. A result of zero is expected for this test case.

IV. Conclusions and Future Work

This channel estimator evaluator leverages flexible mmWave synthetic aperture measurements with hardware models to test channel estimators in 5G propagation channels. We have detailed the essential operation of the evaluator and verified its performance. We are currently testing newly developed models. Future work will utilize this evaluator to provide a testbed for analyzing a novel Monte-Carlo based channel estimator for 5G communications systems.

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