Methods for Channel Sounder Measurement Verification

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***Abstract*—We describe an activity of the 5G mmWave Channel Sounder Alliance to verify the hardware performance of channel sounders operating at mmWave frequencies. Such verification procedures are critical when attempting to compare data from sounders having different architectures in various environments. Two different methods are described and illustrated with simple measurement examples.**

Keywords—channel sounder, measurement verification millimeter-wave wireless system, propagation channel measurement.

I. INTRODUCTION

The 5G mmWave Channel Model Alliance[1] was formed to take a longer, research-oriented view of issues related to channel measurement and modeling than that required by many standards groups. The group's goal is to address issues that impede progress in standards development and hardware optimization.

One key Alliance strength is that participating groups utilize a wide range of channel sounders of various architectures. This allows the group to study representative propagation environments with several different channel-sounder technologies, ultimately resulting in more robust channel models. For example, VNA-based channel sounders provide a high dynamic range, allowing detailed insight into the fading characteristics of a specific environment, but primarily for slowly varying or static channels. On the other hand, sampler-based channel sounders are often fast, providing instantaneous channel information. As another example, some sounders have active antenna arrays capable of resolving the angle-of-arrival of multipath components in the plane of the antenna to within a few degrees, while others have antenna coverage over a hemisphere with nominally lower angular resolution, and yet others use lens antenna arrays for analog multi-beamforming that can provide spatial resolutions comparable to or finer than existing phased arrays.

In order for Alliance members to combine measured data from sounders having different architectures, it is essential to have confidence that each channel sounder is performing as expected. This includes verifying that the resulting measured data and the post-processing routines provide results in agreement with theory. Verified data can then be used to extract statistically representative metrics that feed into channel models, such as path loss and power delay profile.

II. CHANNEL SOUNDER VERIFICATION OPTIONS

The participants in the Alliance have established a channel-sounder verification program [1]. The program allows labs to compare their measured, processed data to theory or to an artifact with known characteristics. Two types of verification are described here, "in-situ" verification, and "controlled-condition" verification.

A. In-Situ Verification

In-situ verification may be conducted during field tests to provide confidence that the channel sounder is behaving as expected. Such verification is conducted in environments that are expected to provide known propagation conditions such as a relatively open area that exhibits free-space or two-ray propagation and path-loss behavior. A second example of in-situ verification includes the prediction of power-delay-(angle)-profile characteristics such as individual multipath component time delays or angles of arrival from map-based knowledge of a room.

As an example, NIST has performed in-situ verification measurements of their 83-GHz channel sounder [2] in the lobby area shown in Fig. 1. The measurements were performed over several separation distances between 4 m and 13 m and the path loss exponent was estimated from the Friis equation [3]

$$PL = \frac{(4\pi d)^2}{\lambda^2} \quad . \qquad 1)$$

Figure 1: NIST lobby area.

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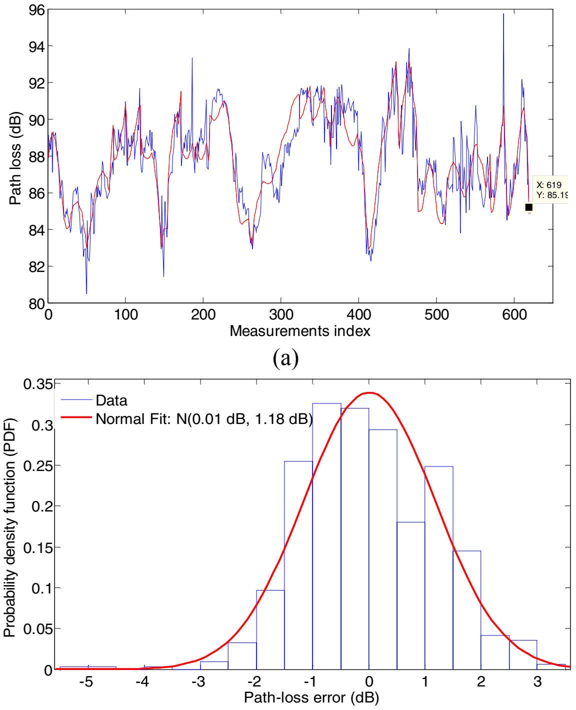
[1] Here "5G" refers to the next generation of mobile wireless communication systems.



(a)

(b)

Figure 2 (a) Temporal variation of the path loss. (b) The measurement error (from [4]).

The Friis equation shows that the received power decreases as the square of the distance *d*. This power of two is an important parameter called the path-loss exponent. Often, the in-situ path loss verification method checks whether measured results produce a path-loss exponent equal to 2 (or very close to 2).

Data were collected while the channel-sounder receiver was in motion. The temporal variation of the path loss and the difference between the theoretical values in (1) and measurements are shown in Fig. 2. [4]. The path loss exponent, estimated from (1), was 1.93 (very close to 2). The nominal transmitter/receiver antenna patterns from the manufacturer were used in the SAGE algorithm [5] since the antennas have not yet been properly calibrated in an anechoic chamber. The maximum variation from the manufacturer's specifications is listed as 2 dB to which we attribute deviations of the data points from the free-space line.

Figure 3: (a) Conference room environment at the NIST Boulder Labs used for power-delay-profile verification.

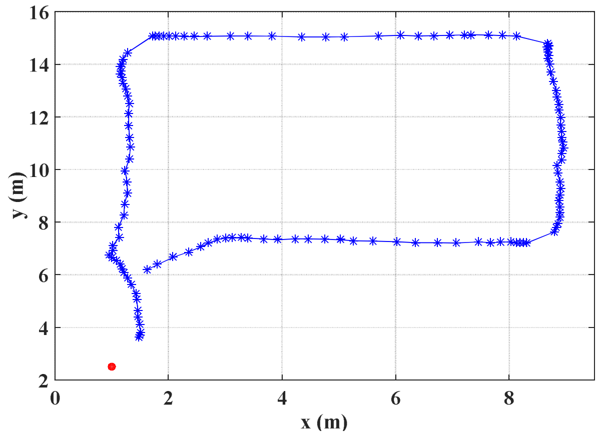
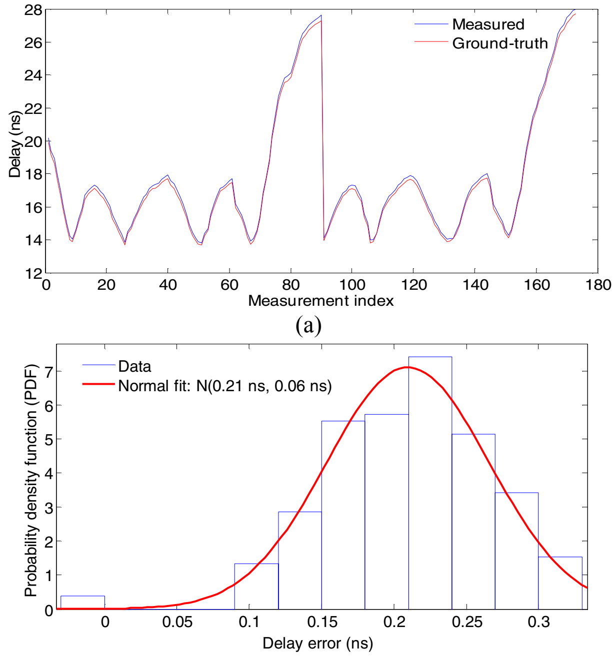


Fig. 4: RX antenna trajectory with measured data points (blue stars) and TX antenna location (red dot).

NIST also performed in-situ power delay profile verification measurements of their 83-GHz channel sounder in the conference room area shown in Fig. 3. The RX antenna positioner was moving during the measurements along the path shown in Fig. 4, while the TX antenna was stationary in the corner of the room at a height of 2.5 m. Each blue star corresponds to a location where data were acquired. These points were used to calculate the signal delay.

The measured and computed delays are compared in Fig. 5(a) and the measurement error is plotted in Fig. 5(b). The results show excellent agreement between the measured and



(a)

(b)

Figure 5: (a) Comparison of measured and computed time delays ("Ground-truth"). (b) The measurement error.

calculated time delays.

B. Controlled-Condition Verification

Controlled-condition verification involves channel-sounder measurements of an environment or artifact having known characteristics, where conditions are determined by design. Here, we report on two types of controlled-condition verification results. First, falling in the category of controlled environments, are measurements made in free-space conditions where reflectors are used to simulate controlled multipath and unintended multipath is suppressed with RF absorbers. Measurements conducted in anechoic chambers would also fall under the controlled-environment verification category. A second type of controlled-condition verification consists of an artifact that provides an artificial-multipath channel such as an electronic channel emulator or an artifact made from coaxial cables of different lengths.

As an example, Georgia Tech has performed path loss verification of their VNA-based channel sounders at 26-43 GHz (Ka-band) and 110-170 GHz (D-band) [6]–[7]. Received power was measured in an open laboratory shown in Fig. 6. Both TX and RX were covered with RF absorbers, as are the floor and surrounding elements. The goal was to eliminate all possible multipath components and create true line-of-sight environment. The TX-RX separation distances ranged from 20 to 180 cm for the Ka-band, with at least 10 measurement points. For the D-band channel sounder, the distances ranged from 30 cm to 85 cm. This range was limited by the transmitted power.

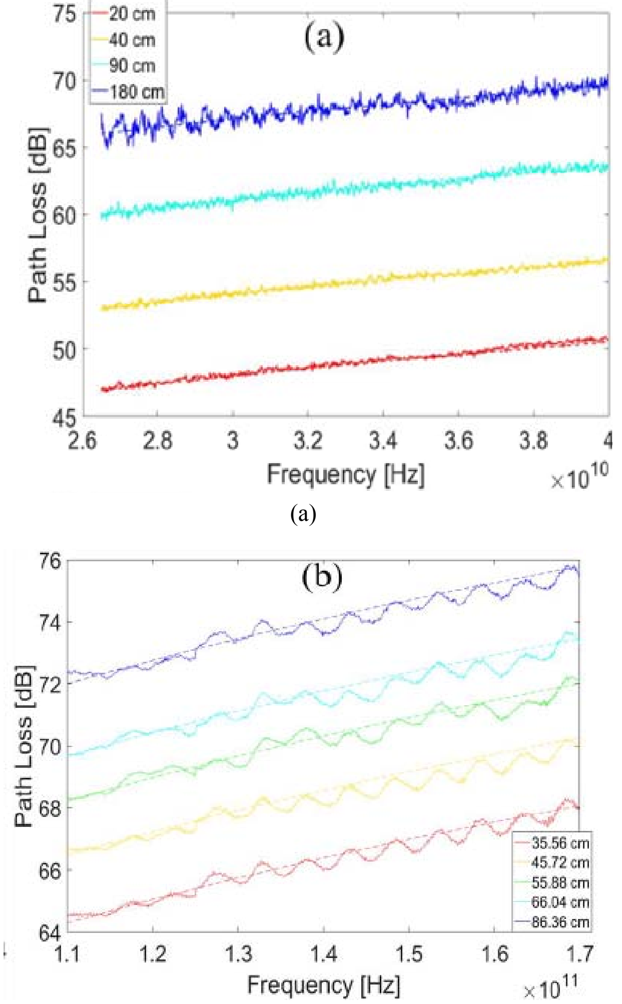
Figure 6: Ga Tech channel sounder. 110-170 GHz measurement setup.

Figure 7 shows that the path loss exponent was estimated as 2.001 for the Ka-band and 1.98 GHz for the D-band measurements. Additionally, a standard deviation of 0.2 dB was observed for both set of measurements [7].

III. BEST PRACTICES FOR VERIFICATION

For all measurement verification methods, utilization of best-practice techniques can maximize the accuracy. Best-practice techniques include, but are not limited to, the following:

- sufficient directionality and correct orientation of the antennas (to avoid transmitting or receiving reflections or scattering, adjustment for movement)
- sufficient time resolution in the measured PDP to ensure that only the first arriving direct LOS over the air path is being recorded (for path loss and timing)
- sufficient distance separation to not overload the receiver (to ensure linear operating range)
- calibration to remove system hardware non-idealities (*e.g.*, back-to-back)
- use of absorbers (and reflectors) to provide controlled environment
- collection of sufficient number of samples to provide statistical significance (*e.g.*, repeat measurements or, if the antenna is mobile, measurements made along a track, and repeated if possible.)



(a)

(b)

Figure 7: Path loss as a function of frequency for several separation distances for (a) Ka-band, and (b) D-band measurements.

IV. SUMMARY

Channel-sounder verification provides a "sanity check" that hardware is operating within expected parameters. This becomes more critical at mmWave frequencies where hardware is pushing the state of the art. Verification allows different labs to confidently utilize data from different but nominally similar environments to develop channel models.

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